World Bank
Government of the People's Republic of Bangladesh

# Gumti Phase II
# Sub-Project Feasibility Study

FAP-5





## FINAL REPORT

## ANNEX C

## GROUNDWATER INVESTIGATIONS

September, 1993

**Mott MacDonald Limited**
*in association with*
**Nippon Koei Company Limited**
**House of Consultants Limited**
**Desh Upodesh Limited**

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**APPENDICES**

## Acronyms

| | | |
|---|---|---|
| Aman | - | Rice planted before or during the monsoon and harvested in November or December |
| AST | - | Agricultural Sector Team (funded by CIDA) |
| Aus | - | Rice planted during March to April and harvested during June and July |
| B aman | - | Broadcast Aman |
| BBS | - | Bangladesh Bureau of Statistics |
| BIWTA | - | Bangladesh Inland Water Transport Authority |
| Boro | - | Rice transplanted in December or January and harvested in April to May |
| BUET | - | Bangladesh University of Engineering Technology |
| BWDB | - | Bangladesh Water Development Board |
| CIDA | - | Canadian International Development Agency |
| DAE | - | Department of Agricultural Extension |
| DHI | - | Danish Hydraulics Institute |
| DOF | - | Department of Fisheries |
| DTW | - | Deep Tube Well |
| ECNEC | - | Executive Committee of the National Economic Council |
| EIA | - | Environmental Impact Assessment |
| EIRR | - | Economic Internal Rate of Return |
| EMP | - | Environmental Management Plan |
| FAP | - | Flood Action Plan - also projects under the FAP eg FAP1, FAP2 etc |
| FCD | - | Flood Control and Drainage |
| FCDI | - | Flood Control Drainage and Irrigation |
| FCD+I | - | FCD initially, then converted to include Irrigation |
| FFW | - | Food For Work |
| FMTW | - | Forced Mode Tubewell |
| FPCO | - | Flood Plan Coordination Organization |
| FRSS | - | Fishery Resources Survey System |
| GM | - | General Model |
| GPA | - | Guidelines for Project Assessment (from FPCO) |
| HTW | - | Hand Tubewell |
| HYV | - | High Yield Variety |
| JICA | - | Japanese International Cooperation Agency |
| JRC | - | Joint Rivers Commission |
| KSS | - | Krishni Sambaya Samity |
| LGED | - | Local Government Engineering Department |
| LIV | - | Locally Improved Variety |
| LLP | - | Low Lift Pump |
| MIKE11 | - | Surface water computer model developed by Danish Hydraulics Institute |
| MLGRD | - | Ministry of Local Government Rural Development |
| MOFL | - | Ministry of Fisheries and Livestock |
| MOIWDFC | - | Ministry of Irrigation, Water Development and Flood Control |
| MPO | - | Master Plan Organization |
| NAM | - | Computer model which derives run-off and groundwater recharge from rainfall |
| NCA | - | Net Cultivable Area |
| NCS | - | National Conservation Strategy |
| NEMAP | - | National Environmental Management Action Plan |
| NFC | - | National Flood Council |
| NPV | - | Net Present Value |
| NPVR | - | Net Present Value Ratio |
| NWC | - | National Water Council |
| NWP | - | National Water Plan |
| ODA | - | Overseas Development Administration (UK) |
| Paddy | - | Unhusked rice |
| RRI | - | Rivers Research Institute |
| SCF | - | Standard Conversion Factor |
| SERM | - | South East Regional Model - a computer hydraulic model of the south-east region of Bangladesh |

| | | |
|---|---|---|
| SERS | - | South East Regional Study - also known as FAP5 |
| SIA | - | Social Impact Assessment |
| SPARRSO | - | Space Research and Remote Sensing Organization |
| SRDI | - | Soil Research Development Institute |
| STW | - | Shallow Tubewell |
| SWMC | - | Surface Water Modelling Centre - the MPO office responsible for the computerized modelling of flows, levels and groundwater |
| SWSMP | - | Surface Water Simulation Modelling Project |
| SSFCDIP | - | Small Scale Flood Control Drainage and Irrigation Project |
| T Aman | - | Transplanted Aman |
| TCCA | - | Thana Central Cooperative Association |
| Thana | - | Small administrative unit (formerly termed upazila) |
| TNO | - | Thana Nirbahi Officer |
| UNDP | - | United Nations Development Programme |
| Union | - | Division of a thana |
| [W] | - | With project - economic evaluation of the future situation with the proposed project |
| [WO] | - | Without project - economic assessment of the probable future value of production if no project is implemented |
| WRPO | - | Water Resources Planning Organization |

## C.1 Introduction

This Annex describes the hydrogeology, groundwater resources and groundwater based irrigation in the Gumti Phase II Study area. The Terms of Reference (TOR) draw special attention to the previous studies of groundwater resources by Annex C of the previous Feasibility Study (BCL/Halcrow, 1990, a.k.a the '1990 Study') and the Draft Regional Plan of the South East Regional Water Resources Programme (FAP:5, a.k.a 'SERS'). The principal objectives set out in the TOR are:

- review the groundwater findings of the 1990 and FAP:5 studies;
- evaluate and map additional data in order to assess the area's developable groundwater potential, including consideration of:
  - hydraulic and water quality characteristics of the aquifer;
  - groundwater flow patterns and hydrographs;
  - inventory of wells and abstractions;
  - the groundwater balance;
  - zoning according to groundwater development potential and technology requirements;
  - environmental consequences of full groundwater development;

The scope of the report goes beyond the Terms of Reference in several regards. First, it considers the effects of various FCD and FCD/I interventions on the groundwater resources. Second important constraints on groundwater development were either not recognised or inadequately addressed in the 1990 and SER studies, and were considered too important to ignore. These constraints are the effects on natural gas discharges on shallow tubewells and (to a much lesser extent on) deep tubewells, and the occurrence of saline water in the deeper parts of the aquifer system in some areas. Neither of the previous studies considered gas constraints, while the SERS had access to only the preliminary results of the Deep Tubewell II Project's investigations into salinity (MMI, 1992) and hence could not present a full evaluation.

## C.2 Previous Work

### C.2.1 General Review

There are a significant number of reports describing the geology and groundwater resources of the Gumti Phase II area. Some details are given in the national reports by UNDP (1982), MMP/HTS (1982) and MPO (1987, 1991). Specific regional studies include:

**Geological Survey. Quaternary Geomorphic Evolution of the Brahmanbaria-Noakhali Area. Bakr (1977).**
An important paper on the geomorphology and Quaternary geology of the project area, emphasising the multiple courses of the Gumti and Titas rivers, especially during historical times.

**UNDP. Hydrogeology of Comilla District. 1981.**
This was the first attempt to produce a comprehensive report on the area, based on nine exploratory holes, pumping tests and water quality analyses. The report still contains valuable data, but has been largely superseded by later work. The work formed part of the national review 'Hydrogeological Conditions of Bangladesh' by UNDP (1982).

**BADC. Deep Tubewell II Project. Phase 1 Completion Report. 1986.**
The report builds on the UNDP/BWDB report, by concentrating on the analysis of the BADC DTWs in the area. A more detailed statistical definition of the lithological profile in each thana was established. The project included a water quality survey and recognised for the first time the existence of saline groundwater in the southern part of Comilla District, although did not identify high salinity water in the Gumti Phase II area. The failure to identify saline groundwater in the west of the study area was due to the almost complete absence of DTWs in that area. The recommendations of this report led to the inclusion of the thanas of Muradnagar, Debidwar, Daudkandi and Brahmanpara and most of Brahmanbaria District in the construction activities of the project.

**MPO. National Water Plan Phase 1. 1987.**
Although national in scope, this project estimated the potential recharge and calculated depth-storage curves for the study area. MPO recognised salinity as a constraint on groundwater development in parts of Comilla and Brahmanbaria Districts, and indicated that this was not due to sea water intrusion, but might be 'correlated with east-west faults cutting across gas bearing Miocene formations at considerable depth'. MPO included part of Debidwar thana as one of their groundwater special study areas.

**BWDB. Hydrogeological Report on Barura, Sharastri, Hajiganj, Chandpur, Matlab, Homna, and Daudkandi (WSP 488). 1987.**

This report was drawn toour attention by comments on Inception Report, and contains *inter alia* chloride and TDS measurements from different depths from BWDB's water quality network. Wells in Homna and Daudkandi thanas in the Gumti Phase II area are included. No water quality problem was identified.

**BWDB. Hydrogeological Report on Barura, Sharastri, Hajiganj, Chandpur, Matlab, Homna, and Daudkandi (WSP 488). 1987.**

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**BWDB. Hydrogeological Map of Greater Comilla (WSP 489). 1987**

This composite map at a scale of 1:250,000 and accompanying panel diagram and tables, is compiled mainly from data in the UNDP (1981) report, BWDB's water level monitoring data and geological data from the Geological Survey of Bangladesh (GSB). Three zones and 12 sub-zones are recognised. No salinity problem was identified. The accompanying tables report values of potential recharge much lower than used by the MPO or FAP studies.

**BARI. Groundwater Resources of Comilla Sadar. Rashid et al. 1988 and 1990.**

A team from BARI carried out a World Bank/BARC funded investigation of Comilla thana. The reports are broad in scope, but cover only a small part of the Gumti Phase II area. No major constraints were identified, but further study was recommended.

**BARD. Irrigation Water Quality in Comilla Sadar. Sharfiullah. 1990.**

Detailed description of water quality at 12 tubewells in Comilla thana; all samples were suitable.

**BWDB. Gumti Phase II Sub-project Feasibility Study. BCL/Halcrow. 1990.**

The '1990 Report' (Annex C of the Final Report) is reviewed in detail in Section C.2.2.1.

**FAP:5. South East Region Water Resources Development Programme. 1991.**

The ongoing 'SERS' study presented analyses of groundwater as part of the 'Regional Plan' and are described in detail in section C.2.2.2.

**BRDB/LGEB. Master Plan for Kachua, Nabinagar, Bancharampur and Debidwar Thanas. JICA. 1991.**

The analysis of groundwater resources given in this report covers the whole of the Gumti region, and is drawn directly from the 1987 BWDB Hydrogeological Map.

**BADC. Deep Tubewell II Project. Final Report. 1992.**

This multi-volume report is the largest source of primary data on the area; the relevant volumes are 2.1 (Natural Resources), 2.1/2 (Groundwater Planning and Monitoring), and 2.1/3 (Groundwater Salinity Study). Of these the most important is the salinity study, which presents a detailed analysis of lithological data from 300 or so

DTW records in the Gumti area, presents regional contour maps of the thicknesses of the aquifers and aquitards, water level maps and aquifer properties. The report identified a range of hypotheses to explain the origin of the saline groundwater, which was recognised (for the first time) to be causing crop damage to irrigated *boro* rice in Muradnagar. The DTW II project carried out a survey of the EC in more than 200 operating wells, and in conjunction with BARI a sub-study of the yield response of rice to saline irrigation water.

DTW II also conducted drilling investigations at two (abandoned) DTW sites of high salinity (5600 and 7200 $\mu$S/cm), which showed that (in the worst areas at least) the two aquifers are separated by a 20-30 metre thick layer of sandy silt; where the upper aquifer is fresh but the lower, main aquifer is saline throughout its depth. It was concluded that the most likely origin of the saline water is that it is connate[1] water remaining from the deposition of the silt layer in an estuarine environment approximately 12-14,000 years ago. Following these conclusions, the BARI study, and a review of international literature, DTW II offered the following guidelines for irrigation water:

| | |
|---|---|
| < 1,000 $\mu$S/cm | unrestricted use |
| 1,000 - 2,000 $\mu$S/cm | unsuitable for vegetables |
| > 2,000 $\mu$S/cm | use for wheat only |

**British Geological Survey. Hydrogeochemistry of N E Bangladesh. Davies and Exley. 1992.**

As part of a regional survey, the British Geological Survey (BGS) collected water samples from the special investigation of the DTW II project in Muradnagar. These groundwater samples have been analysed for major and minor ions and stable environmental isotopes. The results were published during the course of the present study, but BGS made their basic data available in advance of publication, and have been incorporated into Chapter 4.

**Other Data Sources**

In addition BWDB and BADC maintain records of basic data. BWDB maintain a network of piezometers which are measured manually on weekly basis; tabulations of these data are published annually. BWDB also carries out regular water quality monitoring on a limited number of wells. BADC hold construction records of several hundred deep tubewells, of which those constructed under the DTW II Project are available as dBASE IV computer files. BADC also maintains automatic water level recorders in the thanas of Kasba, Debidwar and Muradnagar, and conducts early and late dry season water level monitoring in approximately one operational DTW per union. Results for 1986 to 1991 were published in the DTW II Final Report. Information from the MPO's special study areas in Debidwar is held on file by WRPO and would be helpful.

### C.2.2 Detailed Review of the 1990 and SERS Groundwater Studies

The Terms of Reference require a review of these studies; this section describes the studies in a general way, while section C.2.3 concentrates on the resource potential issues.

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1 The original water in which a sediment was deposited.

#### C.2.2.1 The 1990 Study

The 1990 Study (Annex C of the Final Report) is essentially a review of existing data, concentrating on the lithological data of UNDP (1981) and the potential recharge estimates, and methodology, of the National Water Plan Phase 1 (MPO, 1987). Further data on minor irrigation are contained in Annex H of the 1990 study.

The analysis follows the standard practice in Bangladesh, of defining a depth-storage curve as a basis of predicting the quantities of groundwater available to each tubewell technology. The 1990 Study used the 9 UNDP wells and records of 16 BADC DTWs to construct panel diagrams, and hence assign typical profiles to 14 polygons. The 1990 Study collected no primary data, but did highlight the inadequacy of lithological data in the western and central parts of the area. The 1990 study noted, but did not take explicit account of, UNDP's (1981) observation of 'temporary disequilibrium' of the piezometric surface due to pumping (i.e. effects of layering and pumping from different aquifers). The approach follows the standard practice of the MPO, which does not allow for the effects of layering.

By not checking the water quality of operating tubewells in areas where none existed before 1986, the 1990 Study incorrectly concluded that there are 'no major groundwater quality hazards', and hence did not recognise the extensive occurrence of saline groundwater in the main aquifer. The BWDB did not identify natural gas discharges as a constraint on either suction or force mode tubewells.

#### C.2.2.2 Southeast Regional Study. Draft Regional Plan

In 1991, this component project of the Flood Action Plan produced two complementary reports on the hydrogeology of the area:

- Groundwater Resources and Salinity
- Geology and Groundwater Resources

Together the reports of the South East Regional Study (SERS) contain a thorough review of existing data, and make extensive use of (then) unpublished data from the Deep Tubewell II Project (DTW II), as well as 25 determinations of electrolytic conductivity (EC) in operating tubewells (as a planned supplement to the DTW II survey). For the first time it was recognised that groundwater salinities may exceed 2000 $\mu$S/cm in Muradnagar and Daudkandi thanas. Based on DTW II well records, the study identified the existence of an extensive lower aquitard in the depth interval 30-60 m bgl, in the central part of the study area. The SERS also carried out a detailed reappraisal of the MPO recharge and resource potential estimates; and in particular how these would be affected by full or partial flood protection. The project developed a new model for groundwater planning called the Single Cell Thana Model (SCTM). The model, however, was used with basic data from Phase 1 of the National Water Plan, which appears not to have recognised the importance of the lower aquitard, and as noted earlier was based on insufficient (due to the small number of wells) lithological data in the central and western parts of the area. The model is well suited to evaluating the resource potential of a two layered aquifer system where force mode tubewells may pump from the lower aquifer and suction mode wells from the upper aquifer. SERS defined a salinity limit of 1,000 $\mu$S/cm for irrigation as a planning constraint for the development of groundwater; this is considered to be too conservative for the climatic conditions and agricultural practices of south-east Bangladesh. The SERS also did not identify natural gas discharges as a constraint on either suction or force mode tubewells.

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### C.2.3 Groundwater Development Potential

The resource analysis in the BWDB Study was based upon data and analysis from Phase 1 of the MPO National Water Plan (NWP), whereas the SERS analysis represents mainly an upgrading and revision of the NWP Phase 2 work. However, the SERS was also took advantage of new lithological data from the DTW II project.

Table C.2.1 compares the total groundwater potential by thana as estimated by the various studies. The potentials are given in terms of a depth of water averaged over the full area of the thana, and as such may be directly compared with the net irrigation requirement of *boro* rice, which is around 500mm. From Phase 1 to

Phase 2 of the NWP, recharge estimates were increased substantially in most thanas (except for Nabinagar[2] and Daudkandi). SERS estimates are generally very close to or somewhat higher than the MPO Phase 2 estimates, and notably increased them in Nabinagar and Daudkandi. Compared to MPO Phase 1, SERS estimates of total groundwater potential are increased in every case and with the exception of Bancharampur (for which the MPO did not have a complete data set) they are increased by at least 44%. Even without taking account of existing surface water irrigation or the definition of irrigable, it follows from both the MPO Phase 2 and the SERS estimates, that the vast majority of the area could be irrigated with groundwater (without consideration to technology or cost).

The SERS (as part of a regional plan) did not estimate the irrigated area in the Gumti area, but quotes only thana totals and is therefore not directly comparable. The present study has made use of the AST/CIDA survey of March 1991 (see Chapter 5 for details). The BWDB collected data for the years 1986 to 1989, and used the year 1987 as the basis for design. There are very important differences between the BWDB Study estimates and the more recent estimates. In the BWDB assessment, it assumed that the total 'irrigable' area is about 110,000 hectares, of which only 27,000 ha are currently under irrigation, with about 10-12,000 ha of this provided from groundwater sources. The BWDB Study indicates that "... the present limit for tubewell development is in the order of 35-40,00 ha", and that (in the case of the FCD scheme) "it is unlikely that more than 25-30,000 ha would be irrigable by LLPs" and hence that "... only some 50 - 70,000 ha is likely to have dry season irrigation". However, the 1991 AST survey shows that there is already 65,000 ha under irrigation, of which 27,000 ha use groundwater sources.

The BWDB Study did not give a detailed assessment of current groundwater abstraction, although they did note the difficulty of making accurate estimates. The SERS estimated water use from the numbers of irrigation units operating, and was the first study of its type to take explicit account of the beneficial effects of surface water irrigation in increasing the groundwater potential. The SERS assumes a higher unit rate of groundwater use than the DTW II estimates. The SERS data refer to 1990 and are based on only DTW, STW and LLP numbers (from MPO records) together with synthesised (national average) command areas assuming:

- 1 DTW of 2 cusec capacity irrigates 16 hectares
- 1 DTW is equivalent to 4 STWs (4 hectares)
- 1 LLP is equivalent to 0.8 DTWs (12.8 hectares)

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2 The MPO Phase 2 estimate for Nabinagar is considered unrealistic, and is probably a data processing error.

## TABLE C.2.1

### Comparison of Previous Recharge Assessments

| Thana | *MPO Phase I* Available Recharge (1) mm/yr | *MPO Phase II* DTW1 Potential mm/yr | Change From Previous Estimate | *Southeast Regional Study* Unconstrained DTW1 Potential mm/yr | Change From Previous Estimates MPO I | MPO II |
|---|---|---|---|---|---|---|
| Akhaura | 375 | 738 | 97% | 738 | 97% | 0% |
| Kasba | 300 | 506 | 69% | 613 | 104% | 21% |
| Nabinagar | 390 | 288 | -26% | 673 | 73% | 133% |
| Bancharampur | 400 | 431 | 8% | 431 | 8% | 0% |
| Homna | 375 | 507 | 35% | 540 | 44% | 7% |
| Daudkandi | 375 | 364 | -3% | 539 | 44% | 48% |
| Muradnagar | 345 | 425 | 23% | 708 | 105% | 67% |
| Debidwar | 325 | 566 | 74% | 566 | 74% | 0% |
| Brahmanpara | 290 | 597 | 106% | 496 | 71% | -17% |
| Burichang | 285 | 482 | 69% | 495 | 74% | 3% |
| Comilla | - | 486 | - | 493 | - | 1% |

Notes :

1. As quoted in the BWDB Study (BCL/Halcrow, 1990)
2. For practical purposes the 1 cusec deep tubewell (DTW1) potential is effectively the total groundwater potential.

The DTW II report makes use of the AST-CIDA census data and indicate different average command areas:

- 1 DTW irrigates 19 hectares
- 1 STW or DSSTW irrigates 4.7 hectares
- 1 LLP irrigates 8.3 hectares
- 1 manual tubewell irrigates 0.2 hectares

Thus the area of groundwater irrigation given by SERS is liable to be underestimated, and the area of surface water irrigation overestimated. It may be noted that the DTW II project was able to correlate the AST results for DTWs with its own monitoring of project wells; and further, in the adjacent areas of Greater Dhaka and Kishorganj, found a good correlation between the total irrigated areas reported by AST and those derived from analysis of LANDSAT TM imagery for the same period (MMI, 1992; vol 5.1/1).

In the case of both the DTW II and SERS reports, the volume of groundwater abstracted is calculated from the areas irrigated, and hence the differences noted above are carried over. Southeast used an average net crop requirement for *boro* rice of 625mm, although an analysis by DTW II suggests a somewhat lower figure of about 500mm. Thus in spite of using a lower unit water requirement, in all cases except Bancharampur, the quantity of groundwater withdrawn estimated by DTW II is higher[3]. Even so the differences are quite small compared to the total groundwater resources indicated earlier.

Table C.2.2 compares the DTW II estimate of net groundwater abstraction with the estimated potentials for various technologies given by MPO Phase 2 and the SERS. Net abstraction exceeds the STW potential (MPO II) in eight of the eleven thanas, however, with the exception of Burichang and Comilla, AST reported no DSSTWs in those thanas in 1991 (indicating the potential has not been exceeded). This is not necessarily an inaccuracy in the MPO analysis, but perhaps due to the failure to take account of the beneficial effect of recharge from existing surface water irrigation. In fact, in some thanas this may even exceed groundwater abstraction. The SERS methodology does take account of the recharge from LLPs. Table C.2.2 also suggests that the DSSTW potential has been exceeded in Comilla, Burichang and perhaps Brahmanpara. In Brahmanpara, it has certainly not been exceeded, while in Burichang there are a handful of DSSTWs, probably in the south where dry season water levels are deepest. In Comilla, there were reported to be 103 DSSTWs and 410 STWs. Clearly water levels are a constraint for suction mode tubewells over a large part of the thana, however, DSSTW potential has not been exceeded (except perhaps immediately adjacent to the hills). In no thana does the present abstraction reach even 50% of the estimated potential for (1 cusec, 28 l/s) DTWs.

In summary, it may be concluded on the basis of the previous studies there is some potential for additional STW development in most parts of the project area, considerable potential for more DSSTWs, and great potential for DTW development (in fact probably in excess of demand). However, these assessments have not given sufficient attention to the constraints imposed by saline groundwater, and natural gas discharges in suction mode wells. Further, they have not considered the effect of the lower aquitard, and its implications for the various technologies.

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[3] There is a particularly large difference in the case of Brahmanpara, however, the SERS report contains a definite error in the number of DTWs operating.

## TABLE C.2.2

### Comparison of Current Abstraction with Resource Estimates (1991)

| Thana | Net Groundwater Abstraction mm | MPO Phase II Estimates: STW Potential mm/yr | MPO Phase II Estimates: DSSTW Potential mm/yr | MPO Phase II Estimates: DTW1 Potential mm/yr | Southeast Regional Study: DSSTW Potential mm/yr | Southeast Regional Study: DTW1 Potential mm/yr | Comments |
|---|---|---|---|---|---|---|---|
| Akhaura | 84 | * 74 | 242 | 738 | 190 | 738 | No deep setting reported in 1991 |
| Kasba | 122 | * 101 | 183 | 506 | * 106 | 613 | No deep setting reported in 1991 |
| Nabinagar | 23 | * 16 | 59 | 288 | 126 | 673 | No deep setting reported in 1991 |
| Bancharampur | 49 | 93 | 171 | 431 | 171 | 431 | |
| Homna | 79 | * 78 | 150 | 507 | 178 | 540 | No deep setting reported in 1991 |
| Daudkandi | 47 | * 42 | 85 | 364 | 159 | 539 | No deep setting reported in 1991 |
| Muradnagar | 38 | 65 | 109 | 425 | 142 | 708 | |
| Debidwar | 72 | 84 | 147 | 566 | 113 | 566 | |
| Brahmanpara | 166 | * 132 | 248 | 597 | * 116 | 496 | No deep setting reported in 1991 |
| Burichang | 166 | * 73 | * 134 | 482 | * 134 | 495 | 5% of STWs deep set in 1991, SWL of 9m in S |
| Comilla | 204 | * 86 | * 164 | 486 | * 157 | 493 | 20% of STWs deep set in 1991, SWL of 12m in S |

Notes :

1. * indicates current abstraction greater than estimated potential
2. DTW1 - 1 cusec (28 l/s) Deep Tubewell

## C.3 Hydrogeology

### C.3.1 Geology and Geomorphology

The study area lies between the Meghna River and the Tripura Hills (roughly coincident with the Indian Border). The topography of the area is shown in Figure C.3.1. The surface geology and geomorphology of the area have been described by Morgan and McIntire (1959), Bakr (1977) and Alam et al (1990). The hills and terraces are of Lower or Middle Pleistocene age, while the floodplains are Holocene. The principal landform is the Old Meghna Estuarine Floodplain (also known as the Tippera Surface or the Chandina Deltaic Plain) which is about 1.5 - 2 metres higher than the adjacent than the adjacent Middle Meghna and Surma - Kushiyara River Floodplains, and is characterised by an almost level landscape of smooth broad ridges and basins. Major changes in the drainage pattern have occurred during the last 200 years following the shift in the bulk of the flow of the Brahmaputra to the Jamuna channel. Bakr (1977) has documented a series of westward shifts in the Titas and Gumti rivers in a process of readjustment that is apparently still not complete. It should be noted from Figure C.3.1 that there is a large depressed area of internal drainage near the borders of Homna, Bancharampur and Muradnagar.

**TABLE C.3.1**

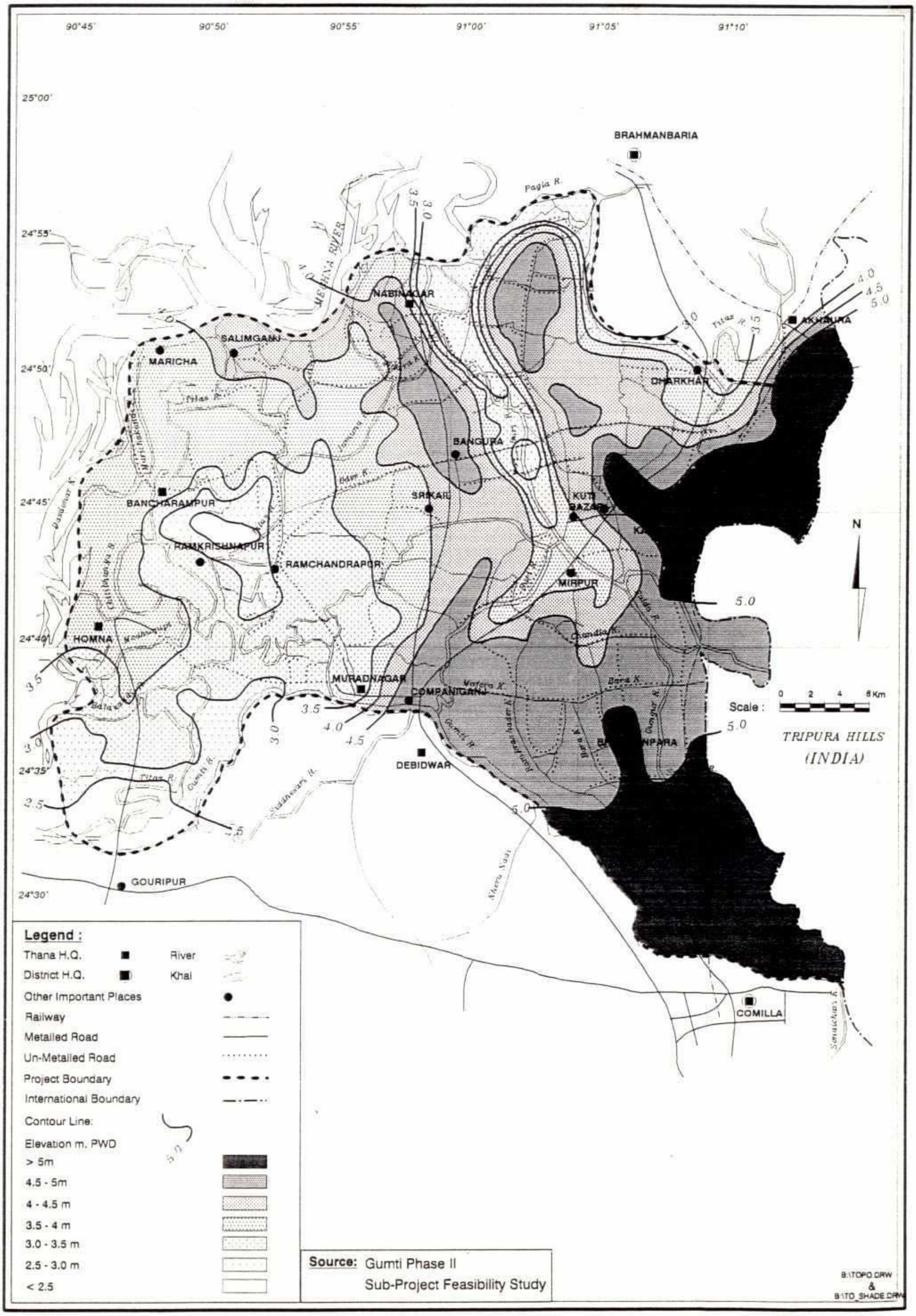
**Stratigraphic Column for Southeast Bangladesh**

| Age | Stratigraphic Unit | Lithology | Reference |
|---|---|---|---|
| Holocene | Meghna river floodplain deposits | alluvial sand and silt | FAO/UNDP (1988), Alam et al (1990) |
| Holocene | Surma - Kushiyara river floodplain deposits | | FAO/UNDP (1988) |
| Late Pleistocene - Holocene | Chandina Formation | Upper sandy sequence<br>Lower silty sequence | Bakr (1977), MMI (1992) |
| Lower Pleistocene | Madhupur Clay | red-brown silty clay (residuum) | Bakr (1977), Monsur (1990) |
| Plio-Pleistocene | Dupi Tila Formation | yellowish brown fine - medium sand | |
| Middle Miocene | Tipam Group | sandstones and shales | Holtrup and Keiser (1967) |
| Early Miocene | Surma Group | mainly sandstone | Holtrup and Keiser (1967) |

The stratigraphic column for this part of Bangladesh is shown in Table C.3.1; only the Dupi Tila and younger strata are exposed at the surface. The area lies on the eastern side of the Bengal Basin and the western flank of the Indo-Burman Ranges, which consist of folded Tertiary sediments. In terms of groundwater development the Tipam and Surma Groups are only of relevance in so far as their folded structure may have influenced the sedimentation of the younger strata. descriptions of the sedimentology and structure of the Tertiary deposits

# Figure C.3.1

## Topography



are given by Holtrup and Keiser (1967), Johnson and Alam (1990) and Khan (1991). The Quaternary geological framework of the area was defined by Morgan and McIntire (1959) and Bakr (1977). The uplifted terrace and hill areas have a cap of Madhupur Clay overlying highly weathered alluvial sands of the Dupi Tila Formation. The Madhupur Clay is now interpreted to be residual soil horizon (Alam et al, 1990) and hence intimately related to the origin of the landforms on which it occurs; Monsur (1990) has used magnetostratigraphic techniques to infer its formation between 730,000 and 900,000 years ago. The deposits underlying the Old Meghna Estuarine Floodplain have been given the name Chandina Formation; radiocarbon dating by the Geological Survey and Brammer (1971) has shown that the surface deposits are no more than about 6,000 years old. The deposition of the late Quaternary sediments was controlled by global sea level fluctuations, in particular during the last glacial maximum of the Pleistocene when sea level fell to about 130 metres below its present level approximately 18,000 years before present (BP), which led to the formation of incised channels along the Meghna and Old Brahmaputra valleys. Thus the definition of the Chandina Formation has been extended to include a transgressive sequence of alluvial and deltaic sediments laid down during the period of rapidly rising sea level between 18,000 and 6,000 BP. The higher elevation of this older floodplain was attributed to tectonic uplift by Morgan and McIntire (1959) but may alternatively be explained by the slightly higher sea levels prevailing between 6,000 and 2,000 BP.

### C.3.2 Groundwater Conditions

The general hydrogeology of the area has been described by Klinski (1981), MPO (1987) and especially in the volume 2.1/3 of the Deep Tubewell II Project Final Report (MMI, 1992). Groundwater is developed for irrigation principally from the Dupi Tila sands, and to a lesser extent the Chandina Formation. For drinking water the proportions are reversed. Despite its importance for public health the volume of groundwater withdrawn for domestic purposes is insignificant compared to that for irrigation. There are very significant abstractions of groundwater by both deep and shallow tubewells (STWs) in most thanas, while abstraction by manual methods is quantitatively insignificant. The groundwater reservoir is recharged annually by infiltration of rainfall and floodwater; the recharge process has been studied in detail by MPO (1987, 1991). The potential recharge estimates are based on infiltration through the top aquitard. However, it has been shown by MMI (1992) that groundwater abstraction often occurs from at least two aquifers in partial hydraulic separation. The semi-confining layer that separates the aquifers is sufficient to maintain different piezometric levels (up to 9 metres in the adjoining areas of Kishorganj) during the dry season while fully recharging both aquifers in the monsoon. Figure C.3.2 shows a schematic (east - west) hydrogeological section through the study area, while Figure C.3.3 shows the thickness of the upper aquitard, the areas where a lower aquitard is present and the thickness of the lower aquitard.

#### Deep Fresh Water Aquifer Hypothesis

Current investigations for the Noakhali North Feasibility Study have clearly shown the existence of a fresh water aquifer below 150 metres in Noakhali and Lakshmipur districts, beneath the brackish/saline aquifer. This aquifer is already being exploited (apparently successfully, but without a formal monitoring programme) by BADC DTWs. Given the apparent similarity of the geology, this lends weight to speculations that there may be an exploitable fresh water aquifer beneath the saline aquifer in Muradnagar. For the purpose of long term planning, this hypothesis is worthy of testing[1]. However, a higher priority should be given to evaluating the potential of the shallow fresh water aquifer, which may be constrained by gas discharges.

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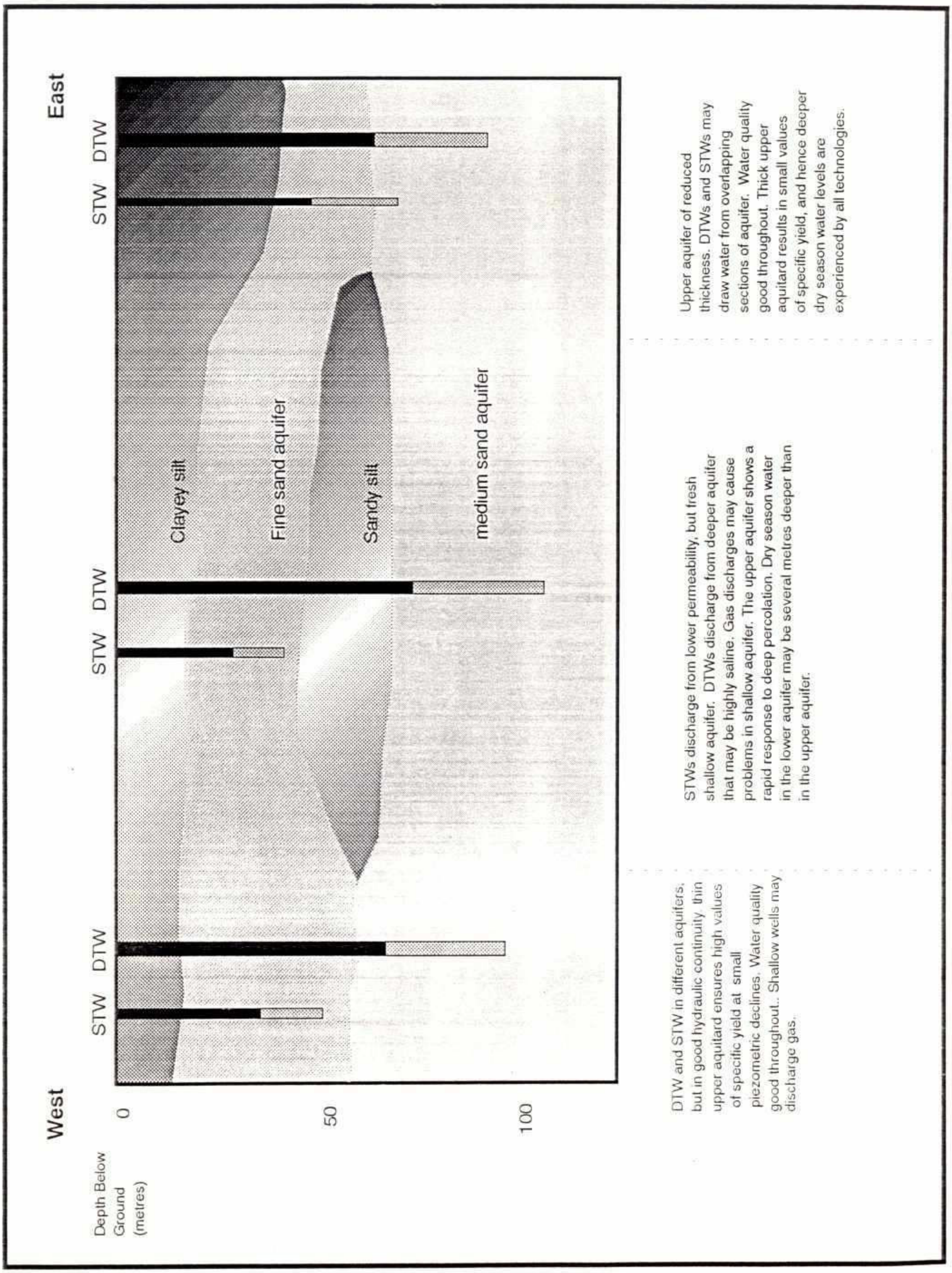
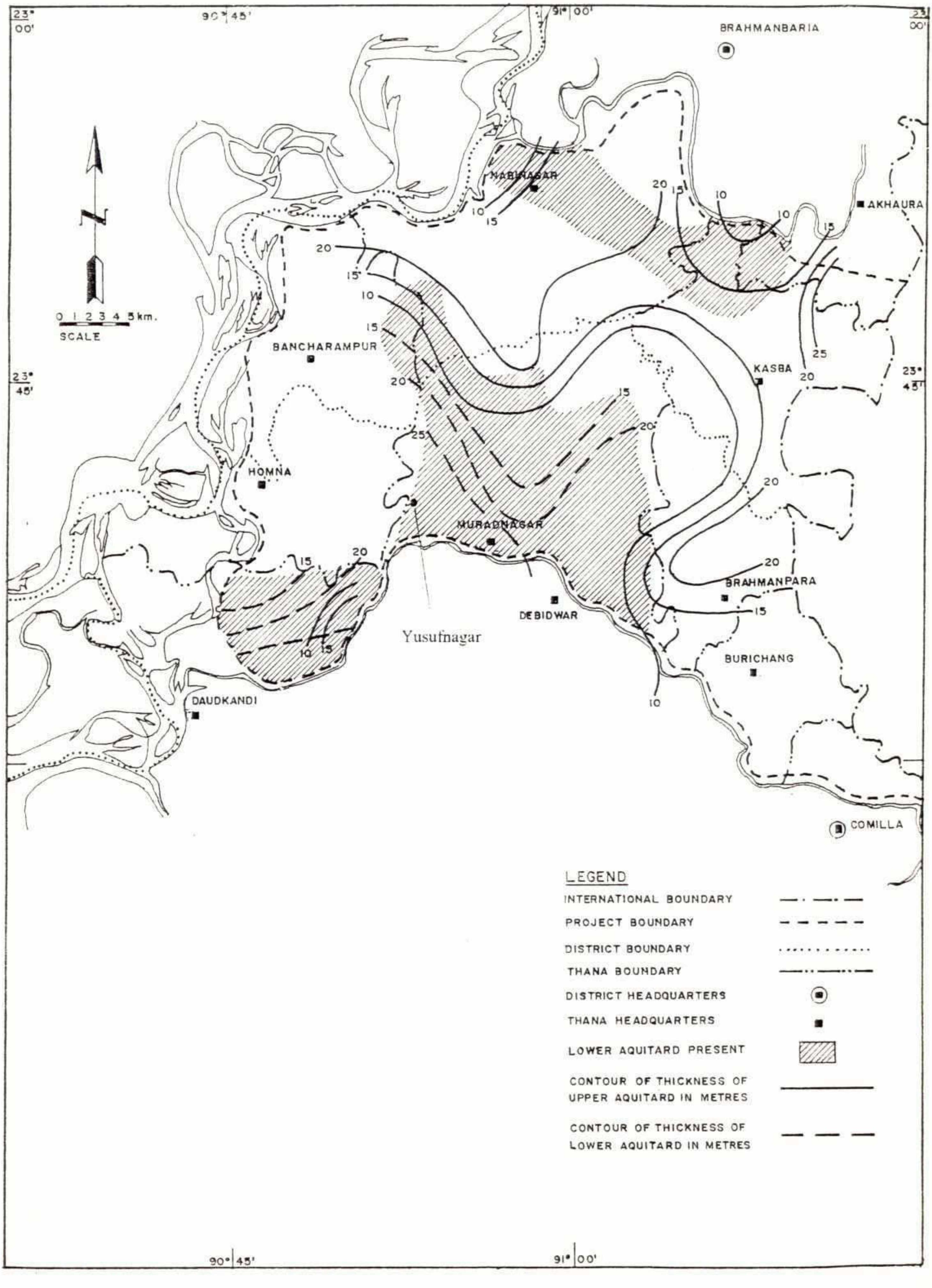
[1] For instance by drilling a borehole to 200 metres at the Yusufnagar test site.

Figure C.3.2

# Schematic Hydrogeological Cross Section Through the Project Area



## Figure C.3.3
## Thickness of Aquitards



### C.3.3 Aquifer Properties

Twelve transmissivity determinations from pumping tests in the Greater Comilla have been reviewed by MMP (1986), BCL/Halcrow (1990) and MMI (1992) and average 724 $m^2/d$ with a standard deviation of 408 $m^2/d$. However, these tests are too few to give an accurate picture of the spatial variability of permeability. A better representation may be obtained from estimating permeability from commissioning tests on DTWs[2]. Individual results are less accurate, but this is far outweighed by the benefits of having around 400 data points in the project area. MMI (1992) smoothed the effect of dubious wells data by contouring union average permeabilities and there is remarkably little variation in the properties of the main aquifer. Thana average permeabilities are given in Table C.3.2. These permeabilities nearly all represent the Dupi Tila Formation, and are comparable with determinations in the greater districts of Dhaka and Mymensingh, however, some wells are almost certainly screened partly in the Chandina Formation are likely to give rise to higher average permeabilities. Despite the smaller average grain size, it is expected that the Chandina Formation will have higher permeabilities because it is basically unweathered, but unfortunately there have been no tests performed exclusively on this unit that could prove this hypothesis.

**TABLE C.3.2.**

**Thana Average Permeabilities of the Main Aquifer**



| Thana | Nr of Wells | Permeability (m/d) | Thana | Permeability (m/d) |
|---|---|---|---|---|
| Daudkandi | | 30.4 | Kasba | 24.6 |
| Muradnagar | | 23.2 | Nabinagar | 27.2 |
| Debidwar | | 22.1 | Bancharampur | 21.2 |
| Brahmanpara | | 22.0 | | |

Analysis of pumping tests generally indicates a leaky aquifer condition and that the specific storages should be in the range of $7 \times 10^{-6}$ to $5 \times 10^{-5}$, and will serve to simulate the short term pumping response of wells. However, monitoring of static water levels shows that over periods of weeks to months the aquifer behaves as a regionally unconfined system, and hence that specific yield is the critical parameter. In Bangladesh, special attention has been given to the variation of specific yield with depth.

Apart from the estimation of potential recharge, the other key component of groundwater resource planning in Bangladesh has been the depth - storage concept. Having determined what quantity might infiltrate to the aquifer in a year, the planner needs to know what will be the lowering of the water table (or piezometric surface) for a given level of abstraction since this determines the type of tubewell technology that will be required. Hence the variation of specific yield must be known. Specific yield may be determined from pumping tests, but this gives an answer for one water level depth (and also tends to underestimate the long term

2 Using the Logan approximation method to calculate transmissivity, and taking the well screen length plus 10% as the effective aquifer thickness.

water level response). The only practical solution is to establish a correlation between lithology and specific yield. This type of analysis is not new, but under the National Water Plan Project it was developed to an unusual degree of sophistication. The MPO's correlation between lithology and specific yield was refined by the DTW II for the northeast of Bangladesh, and these values (Table C.3.3) were used in the present study. The analysis of these data to estimate groundwater potentials for each technology in each thana area described in Chapter 7.

**TABLE C.3.3**

**Correlation Between Lithology and Specific Yield**

| Lithology | Specific Yield |
|---|---|
| Clay | 0.02 |
| Silt | 0.05 |
| Fine sand | 0.09 |
| Medium Sand | 0.15 |
| Coarse sand | 0.25 |

## C.3.4 Groundwater levels

### C.3.4.1 Piezometric Surface

Groundwater levels are monitored routinely by both BWDB and BADC. Figure C.3.4 shows the elevation of the piezometric surface (as measured in BWDB piezometers) in January 1989. The month of january was chosen because the natural recession is well established, but has not been significantly affected by pumping for irrigation, and so gives a good indication of the natural patterns of flow. There are insufficient data points to interpret the detailed pattern of flow around the rivers, and some of the datum elevations in the west might be questioned, however the general trends are clear. Groundwater flow occurs dominantly from east to west, although there are reversed gradients in the Homna and Bancharampur areas, which appear to correlate with the region of internal drainage seen in Figure C.3.1. Generally the hydraulic gradients are low and lateral groundwater flow must be quite slow. There do, however, appear to be steep gradients between the Indian border and the Titas river near Akhaura.

Figure C.3.5 shows the depth to water (as recorded in DTWs) in the drought period of April 1989, which generally represents the deepest dry season groundwater levels on record. It should be noted that the levels were taken at non pumping time, after the wells had been allowed to recover overnight. These measurements are made from the top of the casing on deep tubewells (which are built on raised ground) and so are probably are 0.5 to 1.0 metre more than might apply to shallow tubewells. Also, it may be noted that, even in the same general area, shallow tubewells tend to be sited on lower lying land. The overall pattern is of a very similar depth to water across the area. Water levels lie closer to the surface in Daudkandi, and only in Burichang and Comilla are water levels likely to pose serious problem to suction mode wells.

## Figure C.3.4
## Piezometric Surface : January 1989

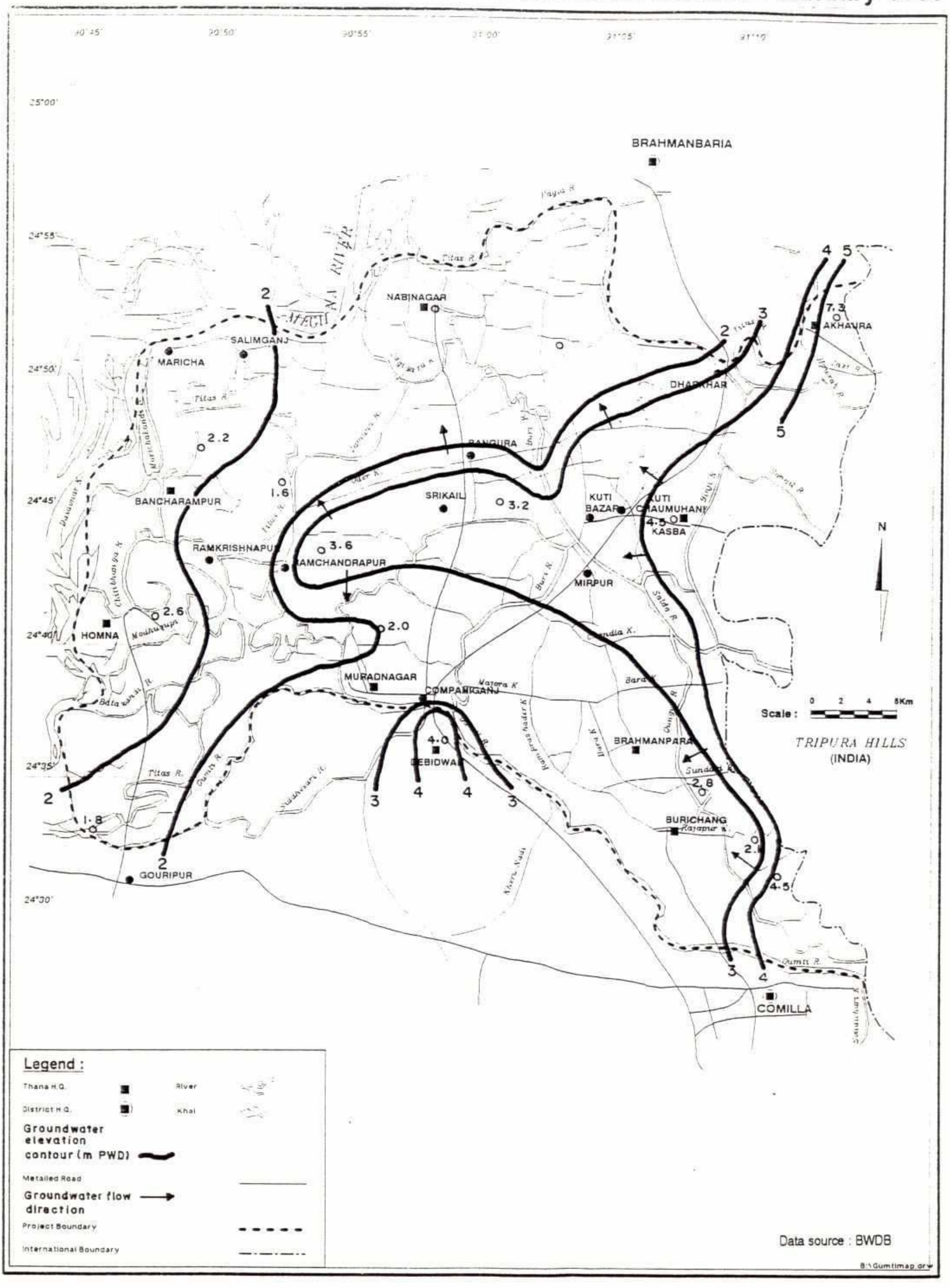
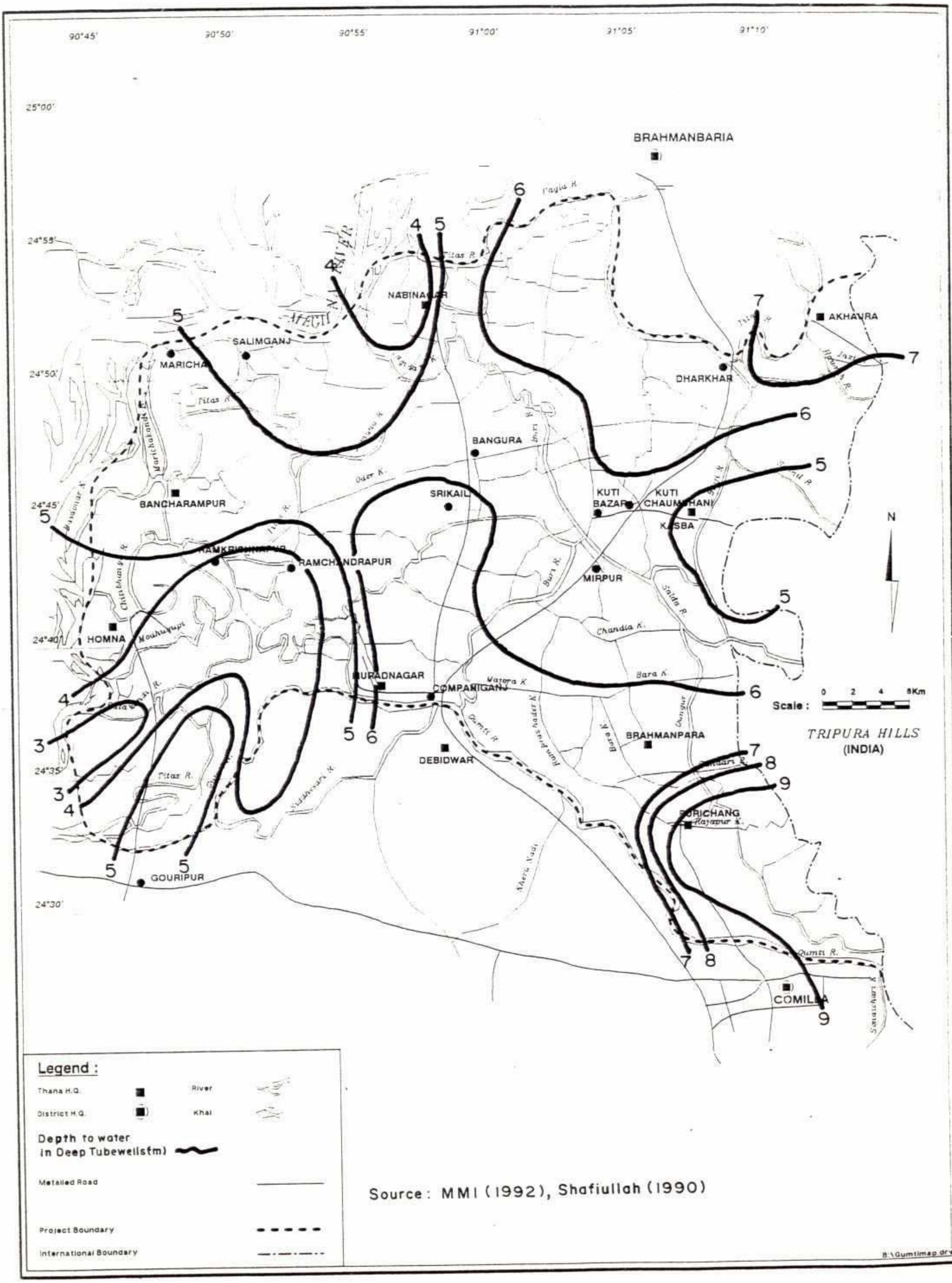


Figure C.3.5
## Depth to Water in the Main Aquifer : April 1989



### C.3.4.2 Hydrographs

Selected groundwater hydrographs from each zone are shown in Appendix C.III, in each case showing both a conventional time series plot, and with several years data superimposed on a common annual scale. All hydrographs show that the aquifers are fully recharged every year, and the broad monsoonal peaks of the hydrographs indicate further that there are usually several months of 'rejected recharge'. Most of the hydrographs show little response to response to pumping (usually a marked inflection of the curve in early February), which as will be shown in Chapter C.7, is not surprising because only Comilla, Burichang, Kasba and Brahmanpara is net groundwater abstraction significantly greater than deep percolation losses from surface water abstraction. Natural recession of groundwater continues into March or April, but any component of the hydrograph due to pumping can only occur between February and April. Hence it can be seen that in all parts of the study area, the effect of pumping is a minor part of the annual fluctuation. Using the abstractions and 'surface water recharges' estimated in Chapter C.7 it is possible to calculate (approximately) the specific yield of the aquifer. The results are shown in Table C.3.4; the calculated specific yield is very similar to that predicted from the lithology (Appendix C.IV) for Kasba, but is somewhat greater than predicted in Burichang.

**TABLE C.3.4**

**Estimation of Specific Yield from Water Level Fluctuations**

| Thana | Burichang | Kasba |
|---|---|---|
| Piezometer | C-002 (BWDB) | BADC Autorecorder |
| Average water level decline from February to April | 3.4 m | 0.70 m |
| Groundwater Abstraction | 190 mm | 122 mm |
| Recharge from surface water irrigation | 25 mm | 52 mm |
| Storage change | 165 mm | 70 mm |
| Calculated specific yield | 0.049 | 0.028 |
| Predicted specific yield | 0.034 | 0.030 |

### C.3.3.3 Monitoring Network

The water level monitoring networks established by BWDB and BADC are generally adequate for keeping a check on impact of groundwater development. However, there is a particular need to monitor levels in both the shallow and deep aquifers where significant force mode development either exists or is anticipated. The principal requirement is to install automatic water level recorder in both aquifers in Muradnagar, and a second recorder in Debidwar so that both shallow and deep aquifers may be monitored. Installation of an automatic water level recorder in Brahmanpara is also recommended.

# C.4 Groundwater Quality

## C.4.1 Groundwater Salinity

### C.4.1.1 Distribution of Salinity

Very detailed field surveys of the electrolytic conductivity (EC) of operating DTWs were carried out in 1991 and 1992 by the DTW II Project (MMI, 1992) and supplemented by a smaller survey by FAP:5 (SERS, 1991). These results represent the salinity of the main aquifer. These surveys could not include the few DTWs in Homna thana, however, one of these (DTW-3 in Homna Mouza) was measured May 1993 and found to have an EC of 800 $\mu$S/cm, which defines a western limit to the area of high salinity in Muradnagar.

The distribution of EC tubewells pumping from the main aquifer is shown in Figure C.4.1. It is seen that there are major variations of groundwater quality in the study area. In the east (roughly corresponding to Zones A and B) the groundwater is extremely fresh ($<250$ $\mu$S/cm). Brackish (defined here as $>$ 2,000 $\mu$S/cm) groundwater occurs mainly in an elongate belt in the west of Muradnagar thana, approximately following the boundary between Zones C and D, and also in small pockets in Zone D. It is emphasised that groundwater in excess of 2,000 $\mu$S/cm occurs only in a small proportion of the study area. Areas of intermediate salinity are conspicuously elongate, being drawn out towards the north or north-east, apparently mirroring the shape of the estuary in which the lower part of the Chandina Formation was deposited, and suggesting the presence of two embayments, in the Nabinagar and Brahmanpara areas.

The SERS and DTW II surveys measured the salinity of adjacent DTWs and HTWs at six sites. In every case the salinity of the DTW was similar to or higher than the HTW. The distribution of salinity in the shallow aquifer (as measured in HTWs and STWs) is similar to that in the main aquifer but the salinity rarely exceeds 1,000 $\mu$S/cm and never exceeds 2,000 $\mu$S/cm.

The DTW II conducted drilling investigations into the vertical distribution of salinity at two of the worst affected DTWs in Muradnagar. There results are summarised in Figure C.4.2, and show that a thick silty aquitard (considered to be the lower part of the Chandina Formation) separates the main and shallow aquifers. The thickness of the upper aquifer is approximately 35 metres and the lower aquifer is approximately 30 metres. The aquitard itself contains the most saline water of all. The main aquifer was shown to be saline from top to bottom. One piezometer was sunk below the main aquifer and showed a slight decrease in salinity[1].

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[1] Combined with recent evidence from Noakhali and Lakshmipur Districts, and chemical characteristics described in Section 5.2, there is reason to think that there may be a deep fresh water aquifer beneath this zone.

Figure C.4.1
## Distribution of Salinity (EC) in the Main Aquifer

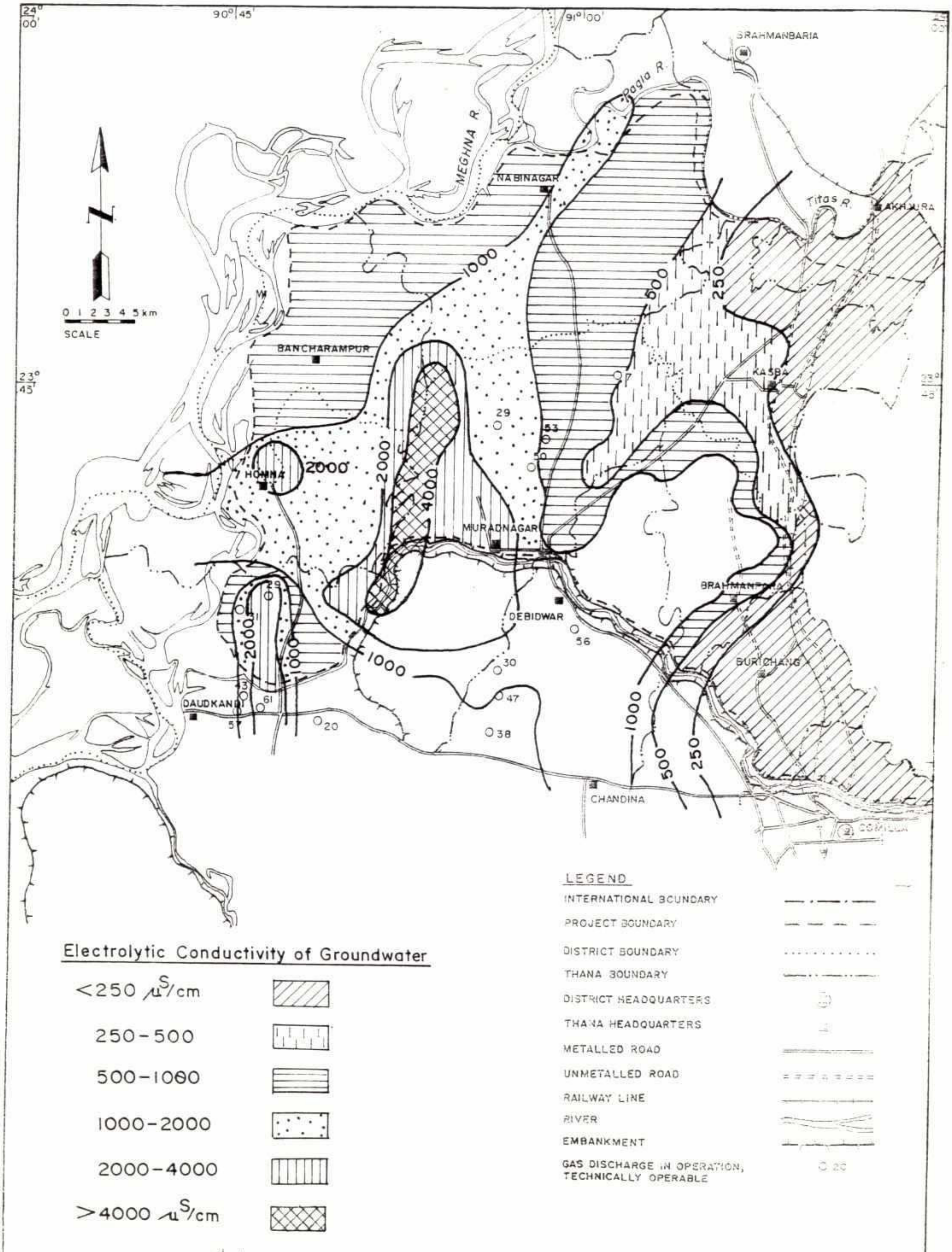
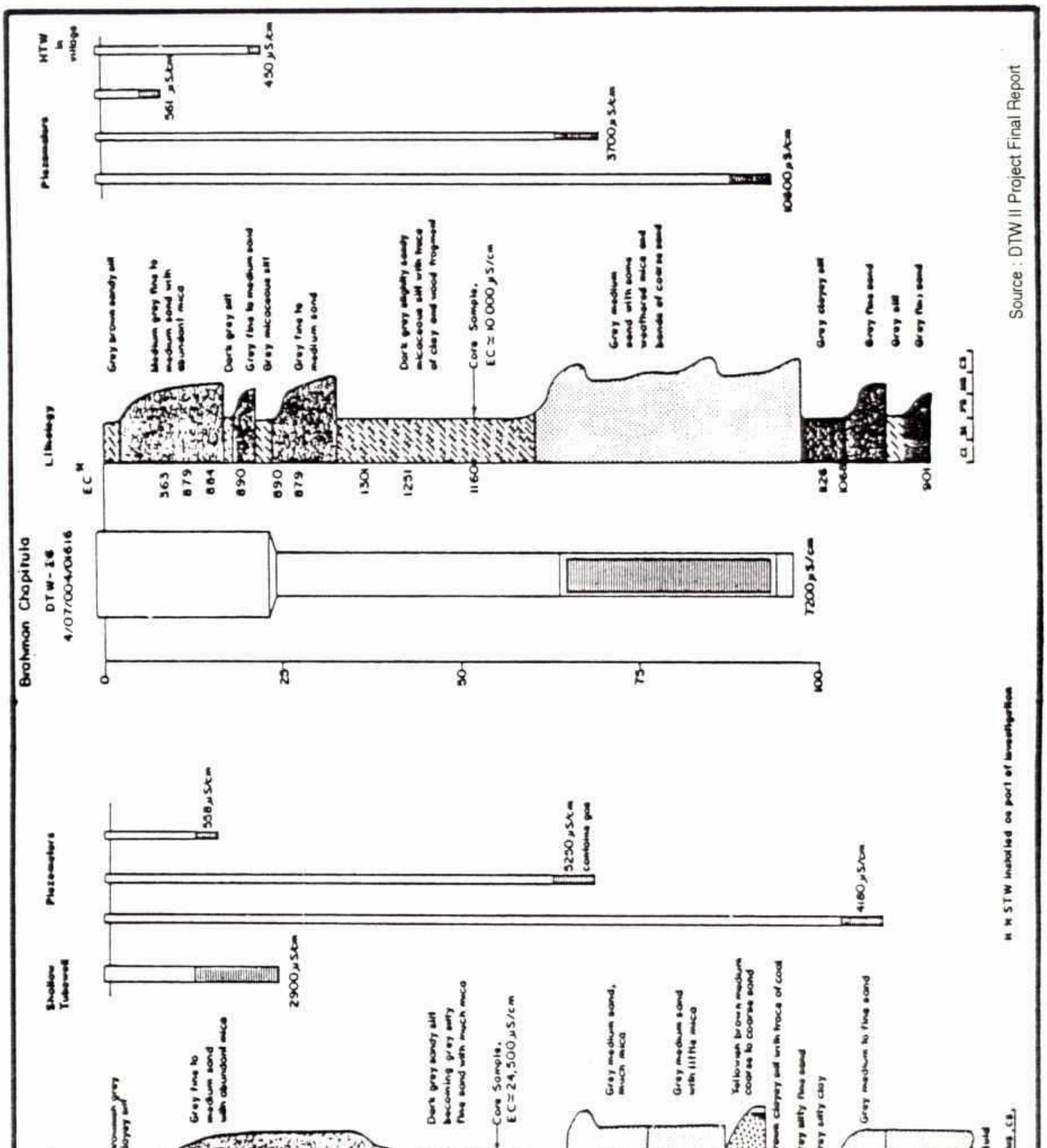


Figure C.4.2
## Groundwater Salinity Investigations in Muradnagar




Source : DTW II Project Final Report

### C.4.1.2 Temporal Trends in Salinity

In May 1993 project staff attempted to measure the salinity of DTWs that had previously been measured in the DTW II surveys of 1985/86 and 1990/91, as shown in Table C.4.1. This certainly does not indicate any deterioration of water quality, and possibly a slight (but probably not significant) improvement.

**TABLE C.4.1**

**Comparison of DTW Salinities with Previous Surveys**

| Thana | Mouza | 1985/86 µS/cm | 1990/91 µS/cm | 1992/93 µS/cm |
|---|---|---|---|---|
| Burichang | Sindurapara | 250 | 210 | Not operating due to non-payment of electricity bill. |
| Burichang | Parawara | 190 | 190 | *ditto* |
| Daudkandi | Gazipur | 280 | 520 | 520 |
| Muradnagar | Bangora | 655 | 600 | 550 |
| Muradnagar | Lazair | 870 | 890 | 810 |

## C.4.2 Water Chemistry

Working in conjunction with the DTW II Project, the British Geological Survey (Davies and Exley, 1992) collected and analysed a large number of water samples from (or very close to) the Gumti Phase II area. That survey was on a regional scale and gave only a brief interpretation of the data from Comilla, while MMI (1992) interpreted the field data and isotopic analyses. The BGS chemical analyses are given in Table C.4.2 and the location of the sampling sites are shown in Figure C.4.3.

The DTW II surveys aimed at differentiating between a (basically) sea water origin of the saline groundwater or leakage of deep formation waters known to exist in the producing horizons of the Bakhrabad Gas Field. The SERS (1991b) identified the deep water as having distinctive Cl/Br and Cl/I ratios quite different to standard sea water. However, no halide ratios were available until the BGS survey. Table C.4.3 shows that the Cl/Br ratios are very similar to sea water, although the Cl/I ratios have a less obvious interpretation.

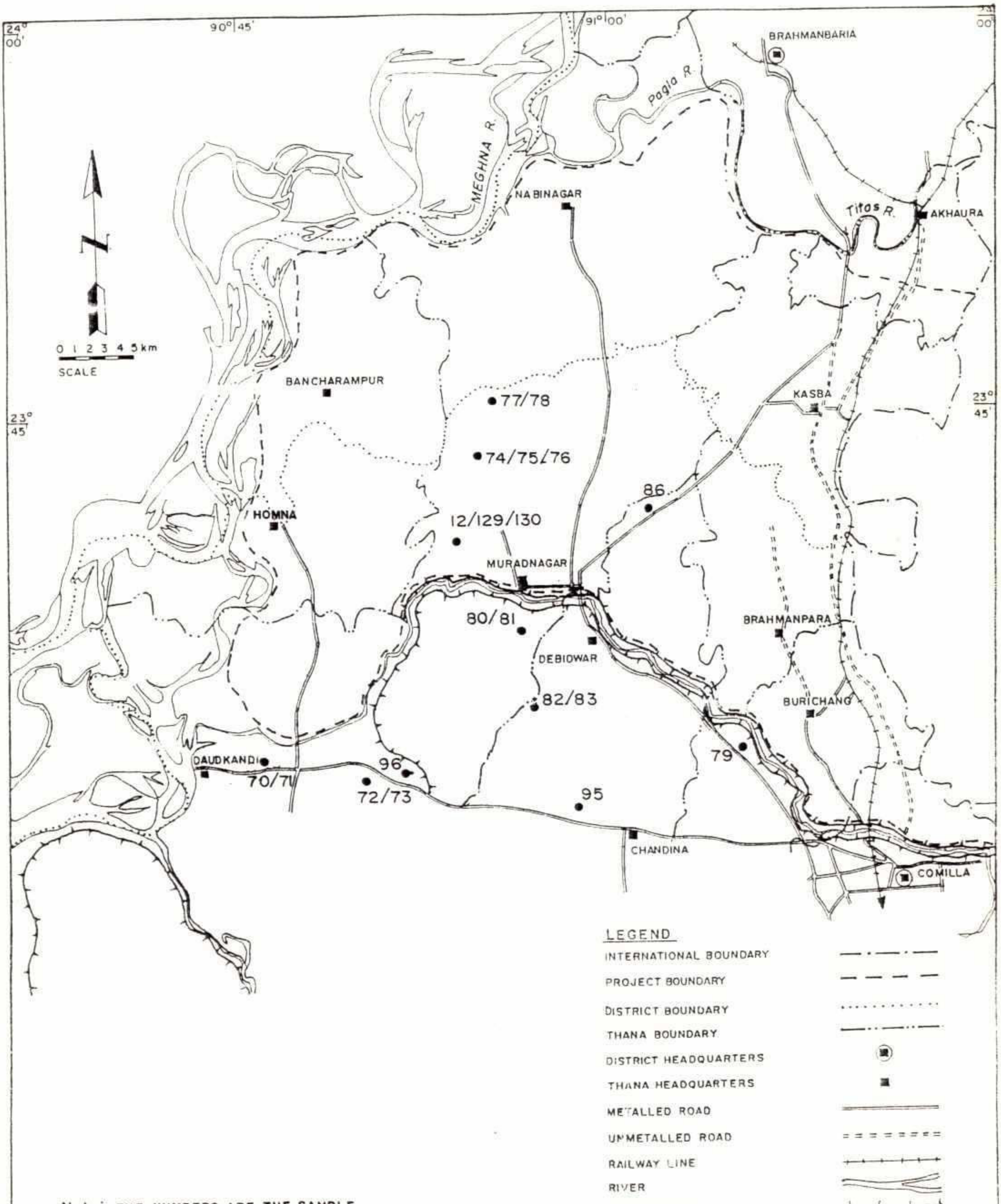
# TABLE C.4.2

## Chemical Analyses of Groundwater from the BGS Regional Hydrochemical Survey

| Sample Number | Bang 70 | Bang 71 | Bang 72 | Bang 73 | Bang 74 | Bang 75 | Bang 76 | Bang 77 | Bang 78 | Bang 79 |
|---|---|---|---|---|---|---|---|---|---|---|
| Lab Number | 920482 | 920483 | 920484 | 920485 | 920486 | 920487 | 920488 | 920489 | 920490 | 920491 |
| Thana | Daudkandi | Daudkandi | Daudkandi | Daudkandi | Muradnagar | Muradnagar | Muradnagar | Muradnagar | Muradnagar | Burichang |
| Source | DTW | HTW | DTW | HTW | HTW | HTW | HTW | DTW | HTW | DTW |
| Date Collected | 15/2/92 | 15/2/92 | 15/2/92 | 15/2/92 | 16/2/92 | 16/2/92 | 16/2/92 | 16/2/92 | 16/2/92 | 16/2/92 |
| Well Number | 24 | 24 | 25 | 25 | 26 | 26 | 26 | 23 | 23 | |
| Village | | | | | B.Chapitala | B.Chapitala | B.Chapitala | Chandnail | Chandnail | |
| Well screen (m) | 70-95 | 18-24 | 71-112 | 12-14 | 63-69 | 94-100 | 6-9 | 30-72 | 19-22 | 58-82 |
| Average depth (m) | 83 | 21 | 91 | 13 | 66 | 97 | 8 | 51 | 21 | 70 |
| Temp C | 28.3 | 25.8 | 26.8 | 25.4 | 25.1 | 25.8 | 25.8 | 26.1 | 25 | 27.3 |
| E.C. (μS/cm) | 1073 | 431 | 950 | 787 | 3700 | 10800 | 567 | 1605 | 921 | 194 |
| Field pH | 6.83 | 7.77 | 6.98 | 7.38 | 7.28 | 6.53 | 7.27 | 7.35 | 7.66 | 6.99 |
| Field Eh mV | 168 | 144 | 182 | 95 | | 275 | 119 | 173 | 72 | 247 |
| | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| Calcium | 63.8 | 49.7 | 63 | 38.5 | 22.6 | 146 | 34.8 | 10.1 | 16 | 9.1 |
| Magnesium | 26.7 | 12 | 23.6 | 46.9 | 24.1 | 161 | 30.9 | 9 | 28.7 | 5.7 |
| Sodium | 94.7 | 32.8 | 80 | 46.5 | 634 | 1610 | 13.8 | 342 | 140 | 24.4 |
| Potassium | 3 | 3.6 | 4.4 | 9.4 | 13 | 27.9 | 5.7 | 5.5 | 9.5 | 2 |
| Manganese | 0.78 | 0.53 | 1.68 | 0.07 | 0.17 | 2.2 | 0.14 | 0.14 | 0.07 | 0.16 |
| Iron | 7.6 | 0.0 | 3.3 | 2.7 | 0.3 | 35 | 10 | 1.5 | 1.1 | 0.8 |
| Zinc | 0.059 | | | | | | | | | |
| Aluminium | | | 0.119 | 1.77 | 0.06 | 1.74 | 0.11 | 0.03 | 0.04 | 0.04 |
| Strontium | 0.398 | 0.168 | 0.435 | 0.342 | 0.239 | 1.37 | 0.219 | 0.104 | 0.203 | 0.079 |
| Barium | 0.133 | 0.02 | 0.105 | 0.035 | 0.061 | 0.112 | 0.017 | 0.024 | 0.006 | 0.014 |
| Lithium | 0.0082 | | 0.0076 | | | 0.05 | | | | |
| Boron | 0.129 | 0.05 | 0.039 | 0.129 | 0.49 | 0.639 | 0.039 | 0.419 | 0.27 | |
| Bicarbonate | 239 | 298 | 180 | 493 | 317 | 141 | 293 | 424 | 580 | 98 |
| Sulphate | 0.1 | | 0.1 | 0.1 | 5.32 | 345 | 2.14 | 0.1 | 0.1 | 0.1 |
| Fluoride | 0.27 | 0.22 | 0.19 | 0.16 | 1.02 | 0.13 | 0.17 | 2.08 | 0.27 | 0.18 |
| Chloride | 265 | | 196 | 37 | 1030 | 3200 | 15.5 | 370 | 35.5 | 3.7 |
| Bromide | 1.24 | | 1.32 | 0.182 | 4.02 | 13.2 | 0.081 | 1.66 | 0.228 | 0.02 |
| Iodide | 0.51 | [illegible] | 0.61 | 0.101 | 0.83 | 1.6 | 0.0204 | 0.47 | 0.111 | 0.0039 |
| Nitrate (NO3-N) | <0.3 | 1.4 | <0.3 | 7.0 | 6.8 | <0.3 | 1.2 | 3.6 | 10.6 | <0.3 |
| Silicate | | 13.8 | 22 | 20.7 | 10.9 | 19.5 | 26.7 | 17.9 | 17 | 28.2 |
| Phosphate | | 1 | 0.6 | 3 | 0.7 | 1.2 | 1.5 | 1.4 | 4.1 | |
| *Isotopic Analyses* | | | | | | | | | | |
| delta H-2 | -21 | | -18 | | -39 | -43 | -18 | -30 | -19 | -40 |
| delta O-18 | -3.5 | | -3.3 | | -5.5 | -6.2 | -1.8 | -4.0 | -2.7 | -5.6 |

| Sample Number | Bang 80 | Bang 81 | Bang 82 | Bang 83 | Bang 86 | Bang 95 | Bang 96 | Bang 128 | Bang 129 | Bang 130 |
|---|---|---|---|---|---|---|---|---|---|---|
| Lab Number | 920492 | 920493 | 920494 | 920495 | 920498 | 920487 | 920488 | | | |
| Thana | Muradnagar | Muradnagar | Debidwar | Debidwar | Debidwar | Debidwar | Daudkandi | Muradnagar | Muradnagar | Muradnagar |
| Source | DTW | HTW | DTW | HTW | DTW | DTW | DTW | Piez. | Piez. | Piez. |
| Date Collected | 17/2/92 | 17/2/92 | 17/2/92 | 17/2/92 | 17/2/92 | 19/2/92 | 19/2/92 | 3/3/92 | 3/3/92 | 3/3/92 |
| Well Number | 7 | 7 | 30 | 30 | | 39 | 9 | 4 | 4 | 4 |
| Village | | | | | | | | Yusufnagar | Yusufnagar | Yusufnagar |
| Well screen (m) | 68-110 | 23-26 | 30-86 | 17-20 | | 55-91 | 63-106 | 103-109 | 63-70 | 19-22 |
| Average depth (m) | 89 | 24 | 58 | 19 | | 73 | 85 | 106 | 67 | 21 |
| Temp C | 26 | 25 | 26.1 | 24 | 22.4 | 25.8 | 26.3 | 25.7 | 26.2 | 25.8 |
| E.C. (μS/cm) | 619 | 645 | 743 | 910 | 2190 | 2310 | 486 | 3930 | 4920 | 1281 |
| Field pH | 6.82 | 7.24 | 7.28 | 7.51 | 6.49 | 6.92 | 6.69 | 6.49 | 6.2 | 6.86 |
| Field Eh mV | 215 | 96 | 163 | 89 | 159 | 237 | 154 | 266 | 84 | 51 |
| | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | | |
| Calcium | 39.1 | 31 | 18.2 | 33.7 | 27.1 | 53.3 | 22.5 | 226 | 103 | 27.4 |
| Magnesium | 17.2 | 31.6 | 21.4 | 30.9 | 24.3 | 35.2 | 10.1 | 101 | 85.2 | 36.3 |
| Sodium | 43 | 39.2 | 86.6 | 107 | 335 | 308 | 43.5 | 304 | 668 | 188 |
| Potassium | 2.7 | 8.4 | 10.6 | 8.5 | 3.2 | 10.1 | 2.2 | 9.4 | 18 | 12.2 |
| Manganese | 0.28 | 0.07 | 0.12 | 0.06 | 0.14 | 0.33 | 0.28 | 2.1 | 0.29 | 0.11 |
| Iron | 7.5 | 2.6 | 1.5 | 1.9 | 3.1 | 4.5 | 10 | 41 | 16 | 1.5 |
| Zinc | | | 0.03 | 0.1 | 0.13 | 0.03 | 0.03 | 3.2 | 0.14 | |
| Aluminium | 0.09 | | | | | | | | | |
| Strontium | 0.28 | 0.261 | 0.229 | 0.273 | 0.241 | 0.393 | 0.177 | 1.47 | 0.92 | 0.30 |
| Barium | 0.032 | 0.014 | 0.079 | 0.016 | 0.048 | 0.118 | 0.125 | 0.345 | 0.606 | 0.014 |
| Lithium | | | | | | 0.014 | | 0.124 | | |
| Boron | | 0.019 | 0.079 | 0.189 | 0.119 | 0.129 | | 0.039 | 0.239 | 0.27 |
| Bicarbonate | 161 | 337 | 220 | 566 | 278 | 176 | 205 | 102 | 434 | 605 |
| Sulphate | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | 43 | 0.27 | 0.1 |
| Fluoride | 0.15 | 0.19 | 0.28 | 0.23 | 0.39 | 0.32 | 0.23 | 0.14 | 0.16 | 0.29 |
| Chloride | 150 | 45.5 | 140 | 54.5 | 530 | 620 | 72.5 | 1190 | 1450 | 178 |
| Bromide | 0.585 | 0.198 | 0.714 | 0.33 | 2.15 | 2.58 | 0.374 | 4.76 | 6.66 | 0.88 |
| Iodide | 0.0401 | 0.0984 | 0.169 | 0.277 | 0.259 | 0.37 | 0.142 | 0.259 | 2.3 | 0.33 |
| Nitrate (NO3-N) | <0.3 | 9.9 | 4.8 | 9.9 | <0.3 | <0.3 | 6.5 | <0.3 | <0.3 | 10.8 |
| Silicate | 27.4 | 19.9 | 15.1 | 17.5 | 19.2 | 19.2 | 24.9 | 27.5 | 22.8 | 11.5 |
| Phosphate | | 2.4 | 0.7 | 2.8 | 0.7 | 0.1 | 1.3 | 0.5 | 3.1 | 2.2 |
| *Isotopic Analyses* | | | | | | | | | | |
| delta H-2 | -28 | -26 | -32 | -20 | -33 | -35 | -26 | -22 | -50 | -25 |
| delta O-18 | -3.6 | -3.7 | -4.8 | -2.6 | -5 | -5 | -3.2 | -4.2 | -7.7 | -4.1 |

Figure C.4.3
## Location of BGS Hydrochemical Sampling Sites




Note: THE NUMBERS ARE THE SAMPLE NUMBERS (THERE PREFIXED "RANG") USED IN THE BGS PEPORT BY DAVIES AND EXLEY (1992).

### TABLE C.4.3

**Chloride/Bromide and Chloride/Iodide Ratios in Groundwater**

| Source | Cl/Br | Cl/I |
|---|---|---|
| Standard Oceanic Water | 292 | 290,000 |
| Shallow Aquifer | 156-230 | 197-760 |
| Main Aquifer | 148-256 | 321-3741 |
| Gas Field Waters | 37-47 | 341-1075 |

The interpretation of the chemical patterns and trends with increasing salinity are summarised in Table C.4.4. The most important trends were investigated by comparing the analyses with a model of simple (non-reactive, non-equilibrium) mixing, assuming chloride to behave as a conservative tracer, between three waters:

- standard ocean water ($Cl^-$ 19,500 mg/l).
- groundwater from 6-9 metres (HTW, sample BANG-76) at Brahman Chapitala in Muradnagar ($Cl^-$ 16 mg/l), which is considered to be screened in the uppermost part of the Chandina Formation.
- groundwater from 58-82 metres (DTW, sample BANG-79) in Burichang ($Cl^-$ 4 mg/l) which is thought to be drawn from the Dupi Tila Formation.

In the interpretation of this model, if simple mixing occurs then the data points plot on, or between the mixing lines. Data points that parallel, but are displaced from the mixing lines may indicating reactions that indicate either flushing or intrusion depending the direction of displacement. The trends for four parameters (Br, K, Na/Cl and sodium adsorption ratio) are shown in Figures C.4.4 and C.4.5. The trends of bromide and Na/Cl ratio very strongly indicate mixing with sea water as the origin of salinity in groundwater. The general pattern is the main aquifers is undergoing flushing as involving loss of calcium and potassium from solution and the addition of sodium through ion exchange and/or dissolution of feldspars. The higher concentrations of potassium and magnesium (in water of equivalent chloride content) in the shallow aquifer reflects the abundance of biotite mica. In many cases such as sodium adsorption ratio and strontium, the one analysis from below the main aquifer (deep aquifer) shows the opposite trend to the main aquifer, or has an extreme value, and in general clearly has a different origin to the water in the main aquifer. In fact, some of the hydrochemical patterns from the deep aquifer point to intrusion of a fresh aquifer by saline water, rather than the flushing of a saline aquifer noted in the main aquifer.

## TABLE C.4.4

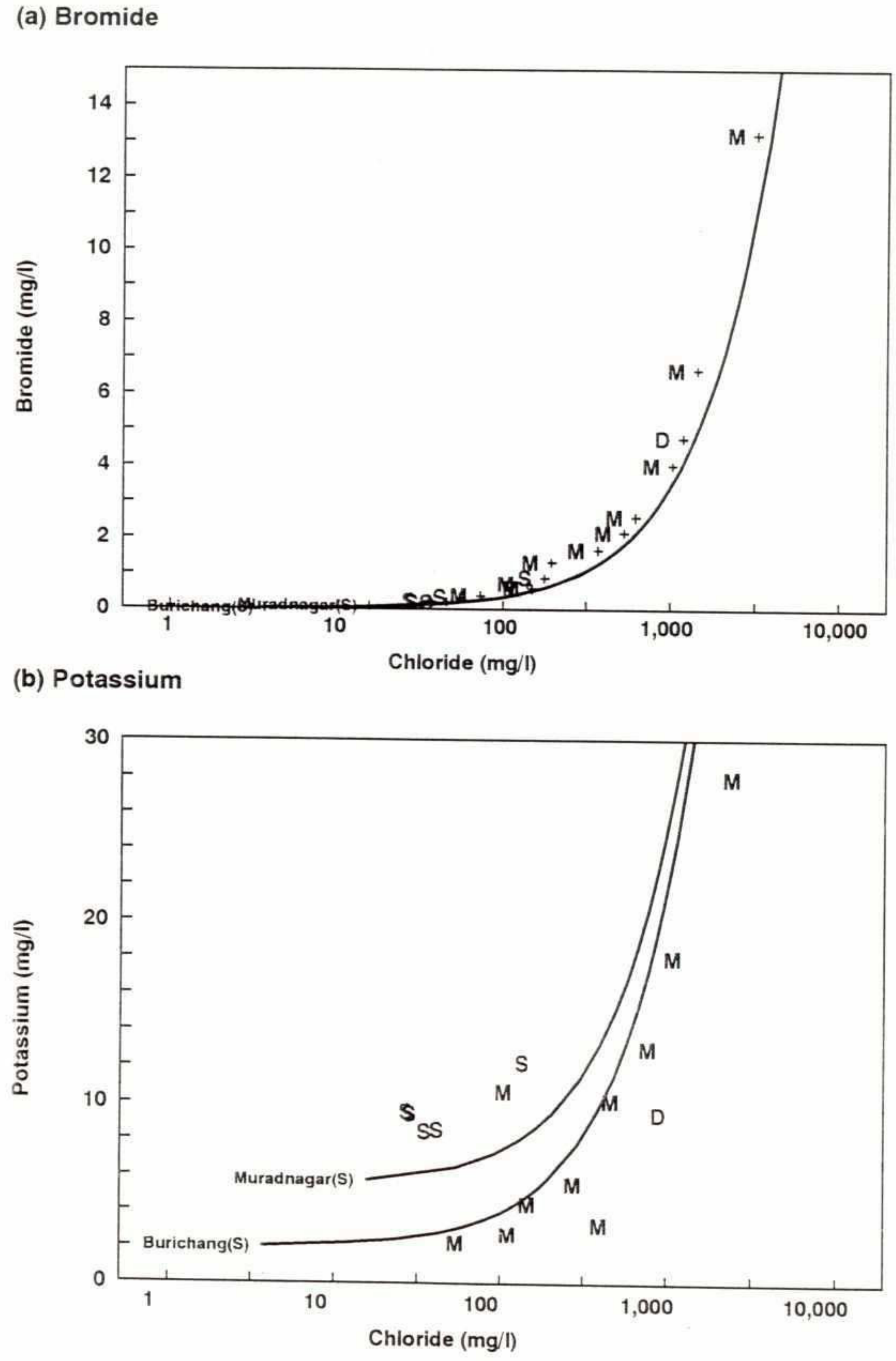
### Hydrochemical Patterns and Trends with Increasing Salinity

| Parameter | Shallow Aquifer | Main Aquifer | Deep Aquifer | Anomalies / Comments |
|---|---|---|---|---|
| Sodium | Wide variation at low salinity | Generally follows simple mixing trend | Depleted with respect to simple mixing trend | |
| Poatssium | Higher concentrations than fresh water in main aquifer. | Parallel to, but depleted with respect to simple mixing trend | Depleted with respect to simple mixing trend | Potassium removed from solution by ion exchange in more strongly leached main aquifer. |
| Calcium | Similar concentrations to fresh water in main aquifer | Rough parallel to mixing trend, but more calicium in solution than predicted | Strongly enriched in calcium relative to mixing line | Main aquifer leached. |
| Magnesium | Higher concentrations than fresh water in main aquifer. | Generally follows simple mixing trend, but depleted depleted in moderate salinity range (Cl 100-1000 mg/l) | Lies close to mixing line | |
| Sodium Adsorption Ratio | Moderate to high SAR | Suggests mixing with sea water combined with ion exchange adding sodium to solution. | Indicates strong depletion of sodium compared to simple mixing. | SAR is considered a good indicator of ion exchange processes. |
| Sodium chloride Ratio | Wide variation at low salinity, highest of project area. | Follows simple mixing trend but with both depletion and enrichment in sodium. | Depleted with respect to simple mixing trend | Na:Cl ratio is considered a key indicator of ion exchange processes. |
| Fluoride | Little variation, similar to main aquifer | Most samples show fall within a small range, similar to the shallow aquifer and compatible with mixing hypothesis | Similar to main aquifer | Main aquifer strongly enriched in fluoride in the north of Muradangar. |
| Bromide | Little variation | Closely follows simple mixing trend | Follows simple mixing trend | Best evidence for sea water mixing hypothesis (Cl and Br are both conservative tracers) |
| Iodide | Lower concentrations than main aquifer, but enriched in iodide | Strongly to very strongly enriched with respect to simple mixing line. Enrichment increases with salinity. | Enriched compared to mixing hypothesis | Iodide enrichment may be due reaction with shallow marine sediments. |
| Sulphate | Very low concentrations | Generally very low concentrations, strogly depleted. One sample follows near mixing line. | Present, but depleted. | Regulated by sulphate reducing bacteria. |
| Phosphate | Contains the highest concentrations | Low concentrations, does not follow mixing tend | Low concentration, not on mixing line | Possible anthropogenic source |
| Boron | Hgher than fresh water in main aquifer | Good fit to simple mixing trend | Depleted with respect to simple mixing trend | Good indication of sea water mixing |
| Barium | Very low concentrations | Enriched compared to mixing hypothesis | Enriched compared to mixing hypothesis | Main aquifer strongly enriched at Yusufnagar (Muradnagar) site |
| Strontium | Similar to fresh water in the main aquifer | Good fit to simple mixing trend | Enriched with respect to simple mixing trend | Good indication of sea water mixing |
| Iron | Mostly <5mg/l, lower iron concentrations than main aquifer | Wide range, generally increases with depth. Highest concentrations in saline water. | Very high concentration | Concentrations probably related to both Eh-pH and sulphate concentrations. |
| Manganese | Lower concentrations than main aquifer | Not related to mixing. Sharp increase below 90 metres. | High concentration | Concentrations probably related to both Eh-pH and sulphate concentrations. |
| Redox Potential | Mosst reducing conditions. No trend with depth. | Relatively more oxidising than shallow aquifer, and generally more so with depth. | Relatively oxidising | Trend with depth opposite to normal pattern (i.e. along a flow path) |
| pH | Generally highest pH. No trend with depth. | Relatively more acidic than shallow aquifer, and a marked decrease with depth. | Relatively acidic | Shallow aquifer buffered by organic matter. |
| Nitrate | Low to high concentrations, always present. | Often below detection limits, but modearte concentraions at some sites. | Not detectable | Potential progressive contamination of aquifer. May act as tracer for modern recharge. |

Notes : 1. Chloride is used as the reference for salinity in the simple mixing model.
2. The end members for the simple mixing model were shallow groundwater from Muradnagar (BANG-76), Burichang (BANG-79) and standard sea water

Figure C.4.4

# Sea Water Mixing Plots - I

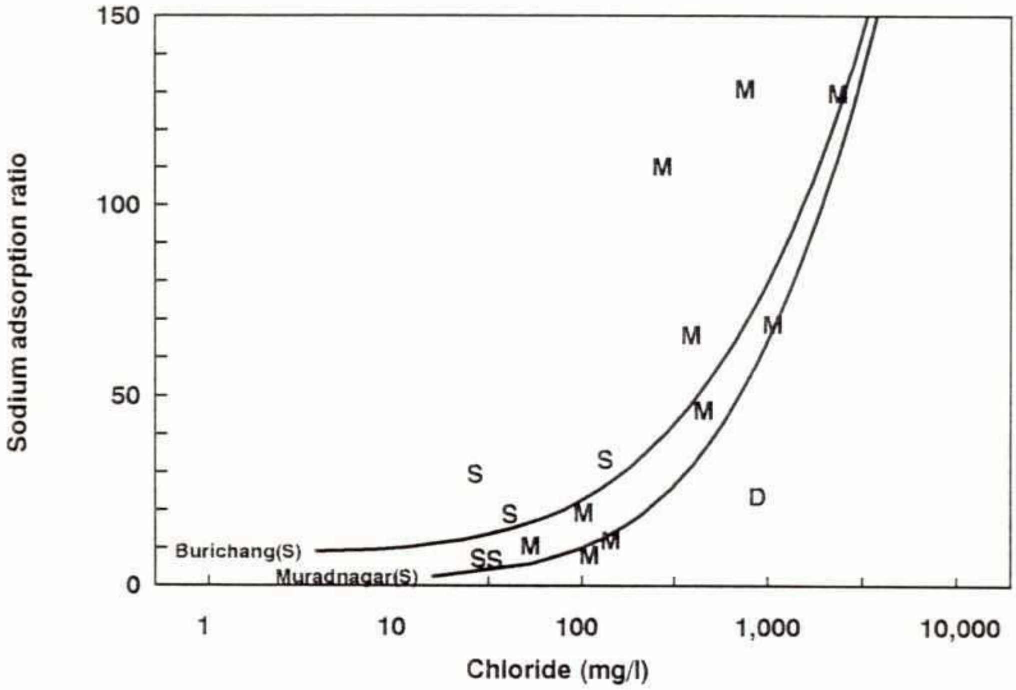



Legend: S - shallow aquifer, M - main aquifer, D - deep aquifer

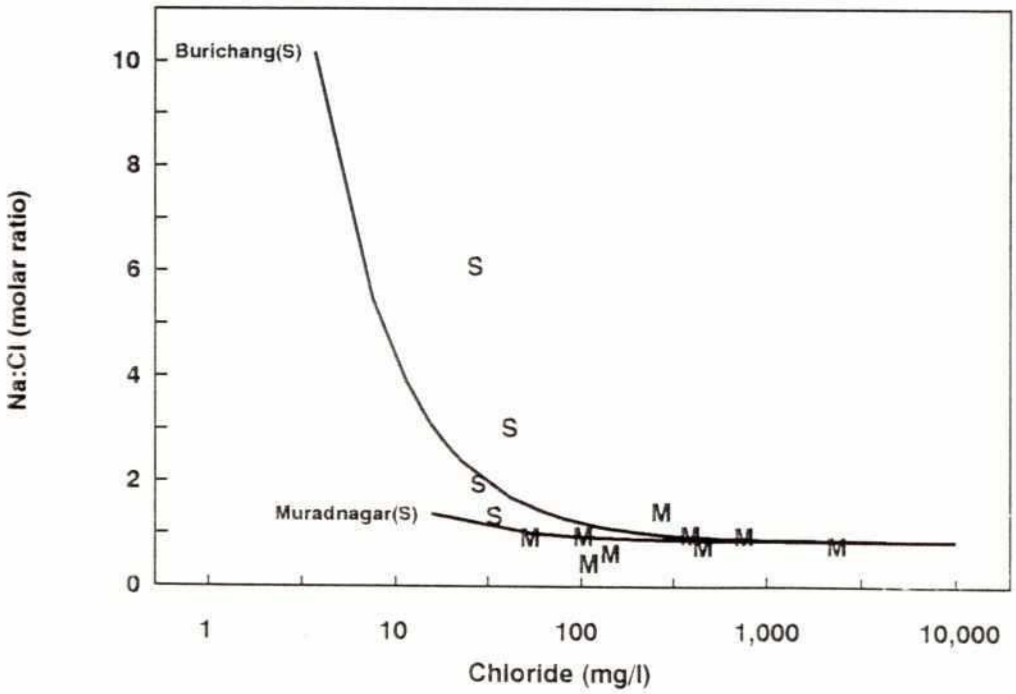
Figure C.4.5

## Sea Water Mixing Plots - II

(a) Sodium : Chloride Ratio




(b) Sodium Adsorption Ratio




Legend: S - shallow aquifer, M - main aquifer, D - deep aquifer

Figure C.4.6 shows the oxidation - reduction (redox) conditions in the aquifers by means of an Eh-pH diagram, on which the concentrations of dissolved iron (in mg/l) are shown as data labels. The diagram also shows the approximate position of the boundary between the (thermodynamic) stability fields of dissolved ferrous iron and solid ferric hydroxide. Almost all waters fall in the stability field of dissolved iron, and are therefore potentially corrosive to steel; while the concentrations of dissolved iron tend to increase in the direction of more oxidising (high positive Eh) parallel to the boundary of the stability fields.The two samples with exceptionally high iron concentrations are both highly saline. The concentrations of manganese in water have a similar pattern to that of iron when plotted on an Eh-pH diagram. What is remarkable about Figure C.4.7 is that there is no overlap between the ranges of the shallow and main aquifers, and even more so that water in the shallow aquifer is consistently more reducing. This is the exact opposite to the pattern that would be expected along a flow path (as source of oxygen are gradually consumed. The implication of this is that the groundwater in the main aquifer is not derived from vertical recharge through the upper aquifer and lower aquitard. Possible alternative explanations are that water in the main aquifer has been emplace by lateral flow, or that it is virtually static and was in place before deposition of the overlying silts and sands.

The BGS study included analysis of stable isotopes of oxygen and hydrogen in water. Davies and Exley (1992) have shown that the isotopic composition of groundwater lies close to the New Delhi and Shillong Hills meteoric water lines, although with some evaporation, indicating that the water originated as rainfall under a broadly similar climatic regime to the present, and therefore by implication not by upward leakage from deep strata. However, water from the main aquifer is isotopically lighter than in the shallow aquifer, indicating that it was recharged under a cooler and/or drier climate than now. The sample from the 'deep aquifer' at Muradnagar is isotopically similar to the shallow groundwater, and further emphasises its different origin to that in the main aquifer. Figure C.4.7 shows that there is a good correlation between $\delta O^{18}$ and chloride, pointing to a connection between the origin of the saline water and particular climatic conditions. A regression line has been fitted to the data from the main aquifer (ignoring the one erratic point); project towards higher salinity this line intersects the chloride content of ocean water (19,500 mg/l) at an isotopic composition of $\delta^{18}O \approx 9.5$. It is well known that the isotopic composition of sea water has varied widely during the Pleistocene ice ages, comparison with the curves of Fairbanks (1989, quoted in Dawson, 1992) shows that the saline groundwater cannot be the product of mixing with pure sea water, that the estuary waters must have been greatly diluted by isotopically light river water.

### Nitrate

Analyses of nitrate in groundwater have been received from the British Geological Survey's (BGS) regional hydrochemical investigation[2]. Samples were collected from deep tubewells, piezometers and hand tubewells for drinking water. Nitrate analyses ranged from below detection limits (0.3 mg/l $NO_3$-N) to 10.8 mg/l $NO_3$-N. The Bangladesh Standard[3] for nitrate in drinking water is 10 mg/l. Figure C.4.8 shows the distribution of nitrate with depth, and also the relationship between nitrate concentrations and redox conditions. The highest concentrations are found in (domestic) hand tubewells in the shallow aquifer, and conversely all samples below detection limits were obtained from below 70 metres. Nitrate concentrations in excess of 10 mg/l in the shallow

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2 Not included in the report by Davies and Exley (1992)

3 The WHO European Standards of 1970 established a 'recommended' limit of 11.3 mg/l ($NO_3$-N) and a 'maximum acceptable' limit of 22.6 mg/l. The WHO International Standards of 1971 took account of higher water intake and bacterial levels in some non-european countries and made 10 mg/l the limit. The US EPA also adopted 10 mg/l. The EEC directive (1980, effective from 1985) makes 11.3 mg/l the maximum admissible level, and 5.6 mg/l the guide level.

Figure C.4.6

## Redox Conditions of Groundwater

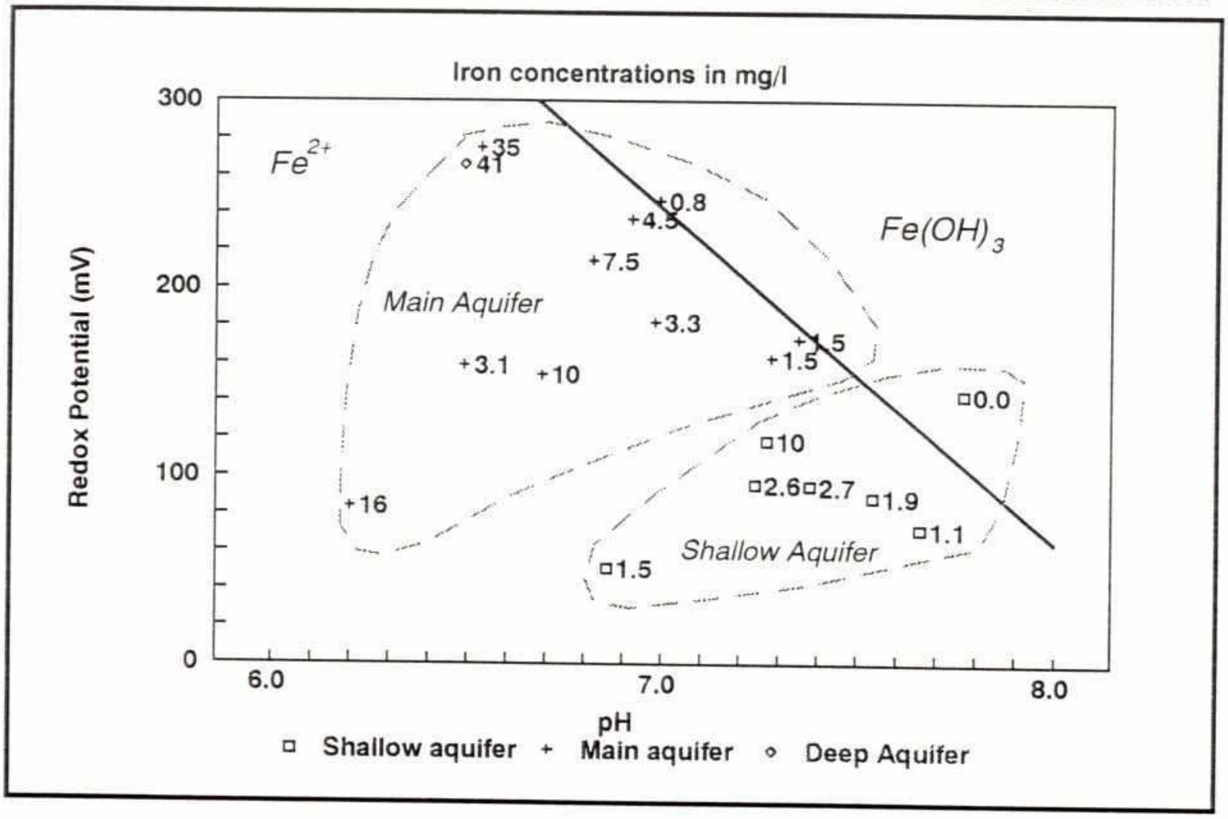



Figure C.4.7

## Variation of Oxygen-18 with Chloride

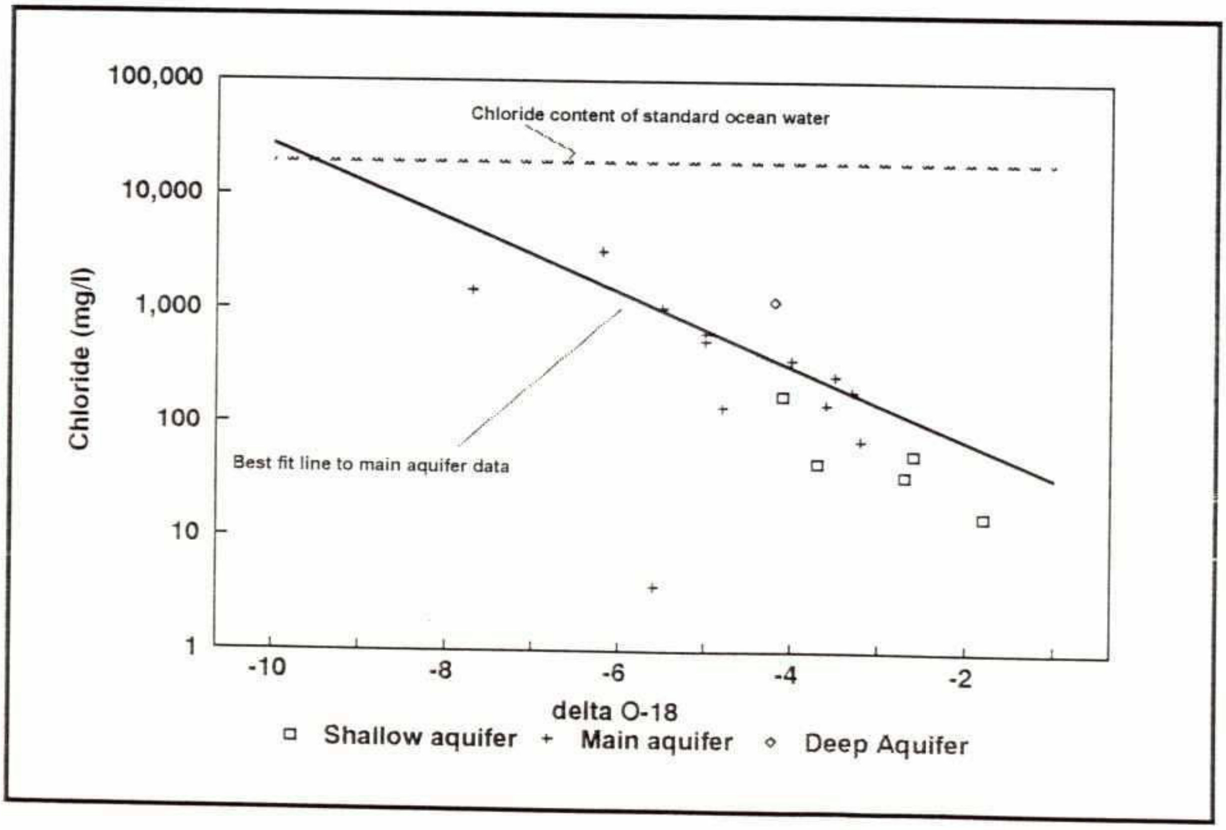
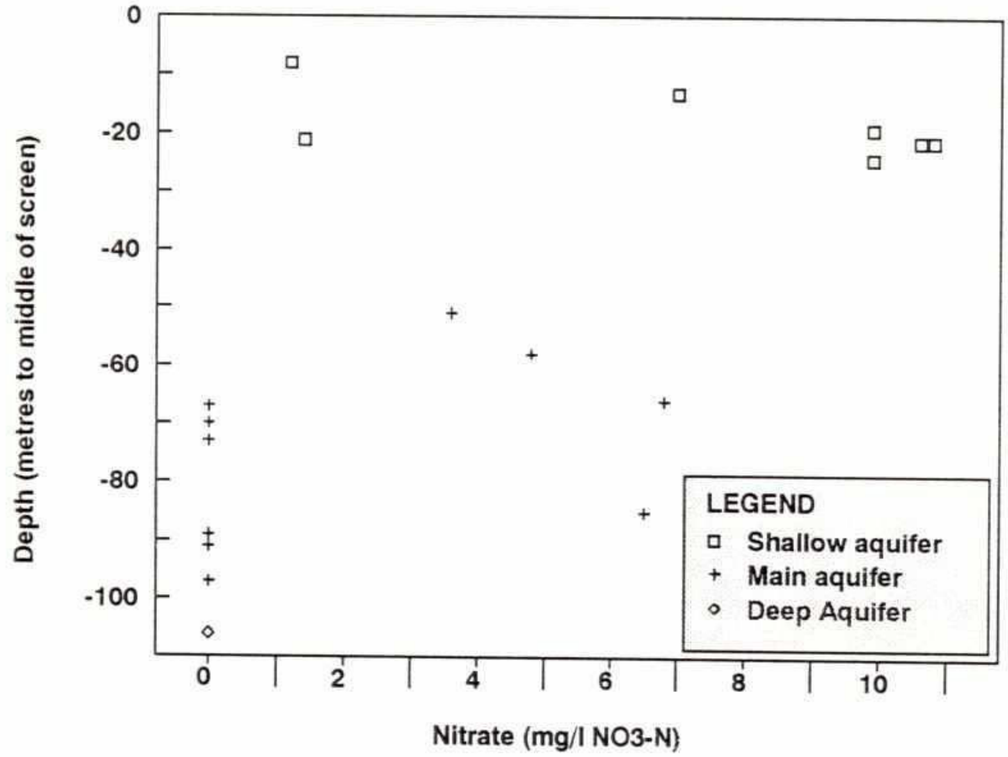


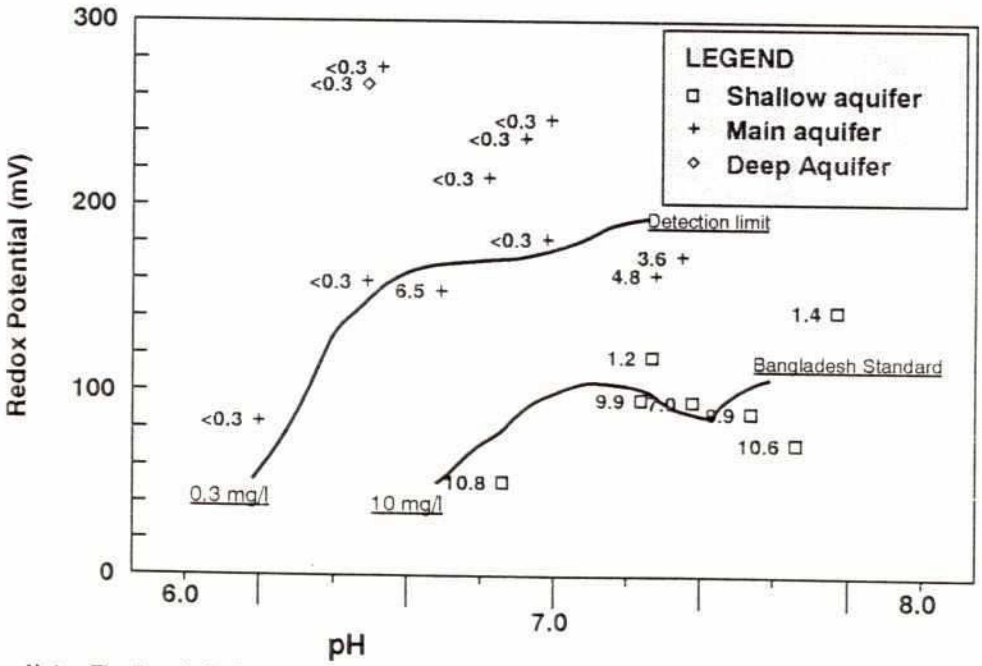
Figure C.4.8

## Nitrate in Groundwater

(a) Nitrate Concentrations as a Function of Depth




(b) Nitrate Concentrations as a Function of Redox Conditions




Note : The Bangladesh Standard for drinking water is 10 mg/l NO3-N aquifer are clearly a concern for public health. Less obviously, but perhaps of equal or greater concern, is that water with nitrate concentrations of 3-7 mg/l have penetrated the aquifer to depths of 50-80 metres. This suggests the possibility of progressive contamination of the aquifer, threatening the practicality of mitigating the nitrate problem by installing deeper wells. Figure C.4.8(b) indicates a strong redox control over nitrate concentrations, and moreover a control that is not directly related to depth. It appears that nitrate acts a tracer for the penetration of modern recharge into the aquifer system. The likely sources of nitrate in the aquifer system are:

(i) faecal sources (human and animal wastes)
(ii) oxidation and leading of organic - N compounds in the soil
(iii) leaching of artificial fertilisers.

In practice, it is often difficult to differentiate between (ii) and (iii) since they are mixed and the same processes control their fate in the soil zone. It is important to differentiate between human and animal wastes on the one hand and agricultural sources on the other, because the policy implications for reducing the long term risks to human health are quite different. If faecal sources are dominant, then the emphasis should be on sanitation:

- increased use, and improved quality, of latrines
- better sanitary protection around drinking water tubewells

however, if the sources are mainly agricultural attention should be given to:

- on-farm management of fertilisers
- post harvest soil management.

The results obtained from the Gumti area are not typical of all areas sampled in the BGS survey (nitrate concentrations were notably low in wells on the Madhupur Tract) but similar conditions may be anticipated in other parts of the Old Meghna Estuarine Floodplain at least, and perhaps over the Holocene floodplains in general. Further investigations and research should be undertaken to determine the extent of the problem, establish a baseline, identify the relative importance of different sources of nitrate, predict long term trends and hence establish a general, but coordinated, strategy to minimise the long term health risks.

### C.4.3 Water Use Criteria

#### C.4.3.1 Drinking Water

No microbiological tests of groundwater quality have been conducted under the project. There is little doubt, however, tubewells offer the best chance of obtaining bacteriologically pure drinking water without treatment. Wherever, significant quantities of nitrate are present in groundwater, bacteria should also be suspected. From a chemical standpoint, the quality of groundwater for drinking is compared with the Bangladesh Standards (very similar to those of WHO) in Table C.4.5, where the analyses have been grouped to draw attention to the differences between the shallow and deep (main for irrigation) aquifer. Currently, the vast majority of drinking water is drawn from the shallow aquifer, but in some areas drinking water is drawn from DTWs during the dry season where suction pumps fail temporarily. This deeper aquifer is also a feasible alternative source of drinking water in the event of the shallow aquifer becoming contaminated.

**TABLE C.4.5**

**Drinking Water Quality of Hand Tubewells and Deep Tubewells**

| Well Type | Hand Tubewells in the Shallow Aquifer | | | | | | | Deep Tubewells in the Main Aquifer | | | | | | | | | Bangladesh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Nr | Bang 71 | Bang 73 | Bang 76 | Bang 78 | Bang 81 | Bang 83 | Bang 130 | Bang 79 | Bang 80 | Bang 70 | Bang 72 | Bang 77 | Bang 82 | Bang 86 | Bang 95 | Bang 96 | Standard |
| Thana | Daudkandi | Daudkandi | Muradnagar | Muradnagar | Muradnagar | Debidwar | Muradnagar | Burichang | Muradnagar | Daudkandi | Daudkandi | Muradnagar | Debidwar | Debidwar | Debidwar | Daudkandi | |
| Source | HTW | HTW | HTW(Piez.) | HTW | HTW | HTW | HTW(Piez.) | DTW | DTW | DTW | DTW | DTW | DTW | DTW | DTW | DTW | |
| Well Screen (m) | 18-2 | 12-1 | 6-9 | 19-2 | 23-2 | 17-2( | 19-22 | 58-8 | 68-11 | 70-95 | 71-11 | 30-7 | 30-8 | | 55-9 | 63-106 | |
| pH | 7.8 | 7.4 | 7.3 | 7.7 | 7.2 | 7.5 | 6.9 | 7.0 | 6.8 | 6.8 | 7.0 | 7.4 | 7.3 | 6.5 | 6.9 | 6.7 | 6.5-8. |
| | mg | mg | mg | mg | mg | mg/l | | mg | mg/l | | mg | mg | mg | mg | mg | mg/l | |
| Calcium | 49.7 | 38.5 | 34.8 | 16 | 31 | 33.7 | 27.4 | 9.1 | 39.1 | 63.8 | 63 | 10.1 | 18.2 | 27.1 | 53.3 | 22.5 | 75 |
| Magnesium | 12 | 46.9 | 30.9 | 28.7 | 31.6 | 30.9 | 36.3 | 5.7 | 17.2 | 26.7 | 23.6 | 9 | 21.4 | 24.3 | 35.2 | 10.1 | 30/5 |
| Sodium | 32.8 | 46.5 | 13.8 | 140 | 39.2 | 107 | 188 | 24.4 | 43 | 94.7 | 80 | 342 | 86.6 | 335 | 308 | 43.5 | 150/20 |
| Potassium | 3.6 | 9.4 | 5.7 | 9.5 | 8.4 | 8.5 | 12.2 | 2 | 2.7 | 3 | 4.4 | 5.5 | 10.6 | 3.2 | 10.1 | 2.2 | 12 |
| Manganese | 0.53 | 0.07 | 0.14 | 0.07 | 0.07 | 0.06 | 0.11 | 0.16 | 0.28 | 0.78 | 1.68 | 0.14 | 0.12 | 0.14 | 0.33 | 0.28 | 0.1 |
| Iron | 0.0 | 2.7 | 10 | 1.1 | 2.6 | 1.9 | 1.5 | 0.8 | 7.5 | 7.6 | 3.3 | 1.5 | 1.5 | 3.1 | 4.5 | 10 | 0.3/1. |
| Zinc | | | | | | 0.1 | | | | 0.059 | | | 0.03 | 0.13 | 0.03 | 0.03 | 5 |
| Aluminium | | 1.77 | 0.11 | 0.04 | | | | 0.04 | 0.09 | | 0.119 | 0.03 | | | | | 0.2 |
| Barium | 0.02 | 0.035 | 0.017 | 0.006 | 0.014 | 0.016 | 0.014 | 0.014 | 0.032 | 0.133 | 0.105 | 0.024 | 0.079 | 0.048 | 0.118 | 0.125 | 0.5 |
| Boron | 0.05 | 0.129 | 0.039 | 0.27 | 0.019 | 0.189 | 0.27 | | | 0.129 | 0.039 | 0.419 | 0.079 | 0.119 | 0.129 | | 1.0 |
| Bicarbonate | 288 | 493 | 293 | 580 | 337 | 566 | 605 | 98 | 161 | 239 | 180 | 424 | 220 | 278 | 176 | 205 | NYS |
| Sulphate (SO4) | | 0.1 | 2.14 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | 300 |
| Fluoride | 0.22 | 0.16 | 0.17 | 0.27 | 0.19 | 0.23 | 0.29 | 0.18 | 0.15 | 0.27 | 0.19 | 2.06 | 0.28 | 0.39 | 0.32 | 0.23 | 1.0 |
| Chloride | | 37 | 15.5 | 35.5 | 45.5 | 54.5 | 178 | 3.7 | 150 | 265 | 196 | 370 | 140 | 530 | 620 | 72.5 | 250/60 |
| Iodide | 0.031 | 0.101 | 0.0204 | 0.111 | 0.0984 | 0.277 | 0.33 | 0.0039 | 0.0401 | 0.51 | 0.61 | 0.47 | 0.169 | 0.259 | 0.37 | 0.142 | NYS |
| Nitrate (NO3-N) | 1.4 | 7.0 | 1.2 | 10.6 | 10 | 10 | 10.8 | <0.3 | <0.3 | <0.3 | <0.3 | 3.6 | 4.8 | <0.3 | <0.3 | 6.5 | 10 |
| Silicate | 13.8 | 20.7 | 26.7 | 17 | 19.9 | 17.5 | 11.5 | 28.2 | 27.4 | | 22 | 17.9 | 15.1 | 19.2 | 19.2 | 24.9 | NYS |
| Phosphate | 1 | 3 | 1.5 | 4.1 | 2.4 | 2.8 | 2.2 | | | | 0.6 | 1.4 | 0.7 | 0.7 | 0.4 | 1.3 | 6.0 |

(dark shading) Parameter exceeds Bangladesh Standard for Drinking Water
(light shading) Parameter between desirable and permissible values
NYS Not yet specified

The most pervasive groundwater quality problems are iron and manganese. Manganese is less of a problem in the shallow aquifer than the deep aquifer, two samples exceed the limit (0.1 mg/l) slightly and only one (0.53 mg/l) exceeds it greatly. All samples from the main aquifer exceed the limit, and have a maximum of 1.68 mg/l. Almost all samples from both aquifers exceed the recommended limits for iron by up to ten times. According to the WHO Guidelines for Drinking Water (1984) both iron and manganese are essential nutrients, but are objected to reasons other than health (such as taste and the tendency to form oxidised precipitates).

Most of the water from the shallow aquifer exceeds the desirable limit for magnesium. The concern over magnesium in water is not clear, but, it is often considered that the sulphates of magnesium, calcium and sodium may cause problems (WHO, 1984). However, since sulphate does not exceed 2 mg/l magnesium this is not like;y to be a problem. The origin of magnesium in the shallow aquifer (as with potassium which exceeds the standard in one sample) is through weathering of the aquifer minerals, and is therefore not expected to increase with time. Sodium (which at high intake levels is linked to heart disease), exceeds the maximum permissible limits in two samples from the main aquifer. In both cases, high sodium is associated with high chloride, and a generally high salinity. These waters which may be acceptable for irrigation, are not recommended for drinking.

Anomalously high concentrations of fluoride and aluminium were noted in single samples in excess of the standards. Analytical and/or sampling errors are suspected, however, these determinations cannot be dismissed, and re-testing is recommended. Nitrate is considered to be a serious long term health concern and was discussed in detail in section C.4.2.

### C.4.3.2 Irrigation

Field investigations carried out by the Bangladesh Agricultural Research Institute (as part of DTW II) concentrated on *boro* rice. However, locally other crops, such as vegetables, may be important near the larger towns or they may be inserted in the cropping sequence prior to boro rice cultivation. Vegetables are generally less salt tolerant than rice and above an $EC_w$ of 1000 $\mu$S/cm some yield reduction is likely, the amount will be dependent upon the salt tolerance of that particular crop. Wheat is an important crop, and has better salt tolerance than rice. Wheat is generally grown as a rainfed crop but could be irrigated with water having an $EC_w$ of 3000 $\mu$s/cm, and would result in a substantial increase in yield compared to rainfed cultivation. At present it appears that the following advisory levels can be set for irrigation water use:

| | |
|---|---|
| $<$ 1000 $\mu$S/cm | unrestricted use; |
| 1000 - 2000 $\mu$S/cm | restrictions on vegetables only; |
| 2000 - 3000 $\mu$S/cm | use only for wheat. |

Salinity is most harmful at certain stages of crop growth such as germination or seed setting. Germination for rice is best effected by using better quality water in the transplant seedling beds. BARC (1990) quote a germination rate of 82% at $EC_w$ of 2000 $\mu$S/cm. Other crops are similarly affected but if they can be germinated on residual soil moisture following the monsoon rains, then irrigated, germination loss can be reduced.

According to BARC (1990) rice yield is not affected by soil salinity either in early growth or the reproductive stage provided $EC_e$ is less than 3,000 $\mu$S/cm. Provided water is maintained on the surface, and an $EC_w$ of 2000 $\mu$S/cm is the upper limit applied then the field water salinity, allowing for some evaporation should not exceed 3000 $\mu$S/cm, which under salivated conditions, should maintain an $EC_e$ between 3,000-4,000 $\mu$S/cm in the root zone. BARC (1990) also report that even higher soil salinities have no effect on the reproduction stage of rice growth. Therefore it appears from the above that the use of water up to $EC_w$ of 2000 $\mu$S/cm is fully justified for the irrigation of boro rice.

For crops other than rice, salinity stress builds up in the root zone as water evaporates from the soil. To counteract this more frequent irrigations will moderate the salinity stress. A further strategy which can be used for row crops (often sensitive to salt) is to use a ridge and furrow system, plant the crop on the side of the ridge and furrow irrigate more frequently than normal. Salts in the water will be moved (and will accumulate) on the tops of the ridges leaving the crop root zone relatively free of salt.

## C.5 Minor Irrigation Development

### C.5.1 Modes of Development

Most data on minor irrigation are collected through either BADC and/or DAE. Until the mid-1980's almost all minor irrigation equipment was distributed through BADC. However, since the privatisation of the LLP and STW sub-sectors, data collection has become inherently more difficult. The BWDB Study carried out its own surveys for the project area for the years 1986 to 1989, and curiously used 1987 as the baseline year for project evaluation. In recent years, rigorous surveys of minor irrigation were organised by CIDA funded Agriculture Sector Team (AST) through DAE. Their 1989 survey recorded only the numbers of equipment operating, while the 1991 also included the irrigated area. Although not perfect, the AST surveys are widely regarded as the best available national data, and their March 1991 survey has been accepted as the baseline for the present resource evaluation. The AST results are shown in Table C.5.1, while Table C.5.2 compares the AST data with those of the BWDB study for the design year of 1987 and the final surveyed year of 1989.

There has apparently been a very rapid growth in irrigation coverage, by both groundwater and surface water, during the last six years, and thus the use of 1987 statistics is quite misleading as regards the current conditions. There is a further complication in that the BWDB statistics do not count the areas irrigated by manual tubewells and traditional methods, which bring the total irrigation coverage in 1991 up to 65,077 hectares. This may be compared with an 'irrigable' area which is probably of the order of 110,000 hectares, but might conceivably be as high as 130,00 hectares. The growth of modern minor irrigation is illustrated by Figure C.5.1 (and Table C.5.3) which shows the numbers of LLPs, STWs and DTWs operating for those thanas that are completely enclosed in the project area. The data have been plotted as the nominal 'cusec equivalent' capacity[1] in order to keep the importance of each technology in proper proportion. These data give a clear indication there was indeed a rapid expansion in all forms of modern minor irrigation during the second half of the 1980's, which gained impetus due to the privatisation of the LLP and STW markets and the extension of the Deep Tubewell II Project into Comilla and Brahmanbaria from 1987. There has been some indication of a reduction in the growth rate in the early 1990's, probably due to the diesel price rises that occurred after the Gulf War. Smoothed forms of the curves shown in Figure C.5.1 would probably give a reasonably reliable indication of the underlying trend. However, it must be mentioned that there are numerous factors, that go far beyond the scope of this feasibility study, that will determine the future demand for irrigation. The most important of these are the Government's policies on privatisation, energy pricing policy, as well as general food policy including import of wheat and the possible establishment of an intervention purchasing policy to smooth the price of rice through the year.

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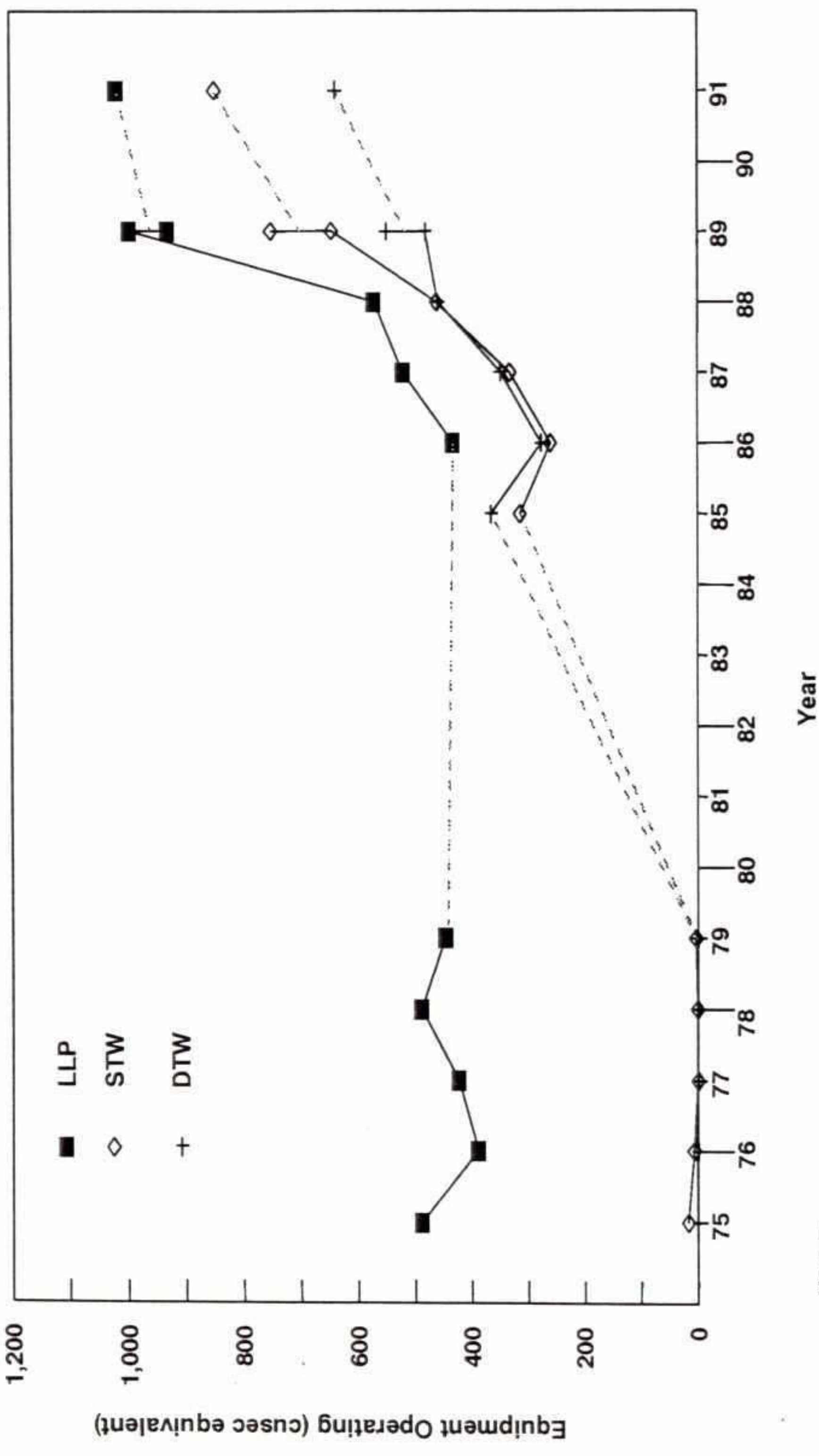
[1] Where DTW = 2 cusec, STW = 0.5 cusec and LLP = 1 cusec.

Figure C.5.1

## Growth of Minor Irrigation




Notes:

1. Data apply only to thanas completely in Gumti area.

2. The two data points for 1989 are from the 1990 Report, and the (higher number from the) AST (CIDA,1989) survey

**TABLE C.5.1**

**Inventory of Minor Irrigation Equipment Operating in March 1991**

| Upazila | Numbers of Equipment Installed: STW | DSSTW | DTW | LLP <1 cs | LLP 1 cs | LLP 2 cs | LLP 3 cs | MTW | Area Irrigated by each Technology: STW ha | DSSTW ha | DTW ha | LLP <1 cs ha | LLP 1 cs ha | LLP 2 cs ha | LLP 3 cs ha | MTW ha | Traditional Methods ha | Total Irrigation ha | Total Irrigation % of Gross area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Akhaura | 156 | 0 | 23 | 50 | 42 | 100 | 1 | 14 | 993 | 0 | 567 | 118 | 263 | 1,225 | 53 | 4 | 1,860 | 5,083 | 80% |
| Kasba | 401 | 0 | 92 | 8 | 52 | 133 | 1 | 55 | 2,614 | 0 | 2,240 | 32 | 488 | 2,094 | 283 | 53 | 1,633 | 9,438 | 52% |
| Nabinagar | 81 | 0 | 27 | 54 | 122 | 360 | 1 | 40 | 645 | 0 | 535 | 311 | 1,354 | 6,769 | 40 | 24 | 677 | 10,355 | 37% |
| Bancharampur | 411 | 0 | 13 | 1 | 45 | 208 | 0 | 442 | 1,937 | 0 | 230 | 1 | 324 | 2,929 | 0 | 79 | 1,735 | 7,236 | 37% |
| Homna | 407 | 0 | 1 | 50 | 108 | 138 | 0 | 4323 | 2,279 | 0 | 20 | 156 | 867 | 1,708 | 0 | 708 | 580 | 6,319 | 41% |
| Daudkandi | 168 | 0 | 13 | 2 | 123 | 233 | 2 | 280 | 1,195 | 0 | 235 | 4 | 1,079 | 3,404 | 162 | 72 | 414 | 6,565 | 63% |
| Muradnagar | 105 | 0 | 51 | 4 | 38 | 168 | 3 | 14 | 852 | 0 | 1,385 | 6 | 476 | 2,965 | 160 | 5 | 206 | 6,055 | 28% |
| Debidwar | 174 | 0 | 7 | 6 | 16 | 30 | 2 | 0 | 811 | 0 | 141 | 12 | 83 | 600 | 81 | 0 | 147 | 1,875 | 28% |
| Brahmanpara | 318 | 0 | 68 | 22 | 9 | 46 | 2 | 1 | 2,389 | 0 | 1,808 | 79 | 93 | 585 | 57 | 0 | 137 | 5,148 | 55% |
| Burichang | 137 | 4 | 91 | 0 | 0 | 34 | 0 | 3 | 803 | 24 | 2,840 | 0 | 0 | 709 | 0 | 1 | 141 | 4,518 | 62% |
| Comilla | 85 | 20 | 32 | 0 | 7 | 30 | 0 | 1 | 552 | 177 | 898 | 0 | 53 | 759 | 0 | 1 | 45 | 2,485 | 69% |
| **Total** | **2,443** | **24** | **418** | **197** | **562** | **1,480** | **12** | **5,173** | **15,071** | **201** | **10,899** | **720** | **5,080** | **23,748** | **835** | **948** | **7,575** | **65,077** | **45%** |

Notes:
1. Source : AST/CIDA (1991)
2. 'See Appendix C.II for full details
3. Data refer to that part of the thana within the Gumit Phase II area.

| | |
|---|---|
| Total Groundwater irrigation by suction mode wells | 16,219 |
| Total Groundwater irrigation | 27,118 |
| Total Surface Water irrigation by low lift pumps | 30,384 |
| Total Surface Water irrigation | 37,959 |



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## TABLE C.5.2

### Comparison of Minor Irrigation Estimates

| Irrigation Mode | 1987 (BWDB) | 1989 (BWDB) | 1991 (AST) |
|---|---|---|---|
| LLP | 15,725 | 24,519 | 30,384 |
| STW & DSSTW | 5,888 | 12,517 | 16,219 |
| DTW | 5,414 | 7,625 | 10,899 |
| **Total** | **27,027** | **44,661** | **57,502** |

Note : All numbers in the table are total irrigated areas in hectares.

The most rapid expansion of minor irrigation has occurred with shallow tubewells, which is particularly striking since (as will be shown in Chapter C.6) they are unable to operate in a significant part of the project area. In general, deep setting of STWs is limited importance in the study area. In many cases, DSSTWs are probably not a permanent method of irrigation, but rather a seasonal response to drought. The numbers of deep set wells in recent years are given in the AST/CIDA surveys.

It appears from Table C.5.4 that deep setting is only a normal condition in Burichang and Comilla thanas, and that in the rest of the study area STWs are not currently constrained by water levels. This conclusion is entirely consistent with the piezometric surface map shown in Chapter C.3. A possibly contradictory note was sounded by the public participation meetings, which frequently recorded the view that STWs suffer from deep water levels in April. This may just be the natural decline in discharge to be expected from any suction pump when the groundwater level is falling. It appears that this is an acceptable inconvenience to most farmers, otherwise they would set the pump in a pit to 'save' their crop.

## TABLE C.5.3

### Growth in Numbers of Minor Irrigation Equipment

| Thana | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Low Lift Pumps (all sizes)*** | | | | | | | | | | | | | | | | | | |
| Akhaura | | | | | | | | | | | | | 70 | 78 | 91 | 149 | | 193 |
| Kasba | 154 | 169 | 170 | 176 | 212 | 182 | | | | | | | 150 | 171 | 130 | 158 | | 194 |
| Nabinagar | 312 | 333 | 334 | 331 | 355 | 335 | | | | | | | | | | 606 | 540 | 644 |
| Bancharampur | 164 | 197 | 136 | 140 | 156 | 152 | | | | | | | 94 | 137 | 170 | 257 | 350 | 254 |
| Homna | 92 | 122 | 83 | 107 | 121 | 112 | | | | | | | 82 | 98 | 140 | 198 | | 296 |
| Daudkandi | 241 | 269 | 257 | 255 | 310 | 252 | | | | | | | | | | 760 | | 772 |
| Muradnagar | 114 | 134 | 107 | 93 | 100 | 97 | | | | | | | | | | 449 | | 375 |
| Debidwar | 73 | 77 | 81 | 49 | 52 | 52 | | | | | | | | | | 179 | 192 | 101 |
| Brahmanpara | | | | | | | | | | | | | 35 | 35 | 39 | 166 | | 79 |
| Burichang | 70 | 81 | 82 | 77 | 71 | 70 | | | | | | | | | | 80 | | 59 |
| Comilla | 76 | 66 | 77 | 82 | 71 | 69 | 75 | 106 | 102 | 96 | 90 | 89 | 104 | 313 | 282 | 270 | | 122 |
| **Total** | **1,296** | **1,448** | **1,327** | **1,310** | **1,448** | **1,319** | **75** | **106** | **102** | **96** | **90** | **89** | **535** | **832** | **852** | **3,272** | **1,082** | **3,089** |
| ***Deep Tubewells*** | | | | | | | | | | | | | | | | | | |
| Akhaura | | | | | | | | | | | | 11 | 10 | 8 | 13 | 11 | | 23 |
| Kasba | 0 | 12 | 33 | 46 | 54 | 52 | | | | | | 113 | 84 | 83 | 82 | 73 | | 92 |
| Nabinagar | 0 | 0 | 0 | 1 | 5 | 9 | | | | | | 29 | | | | 7 | 26 | 34 |
| Bancharampur | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | 0 | 0 | 0 | 0 | 16 | 13 |
| Homna | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | 0 | 0 | 0 | 0 | | 1 |
| Daudkandi | 0 | 0 | 0 | 3 | 4 | 12 | | | | | | 37 | | | | 21 | | 84 |
| Muradnagar | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 10 | | | | 13 | | 62 |
| Debidwar | 19 | 35 | 24 | 38 | 45 | 65 | | | | | | 89 | | | | 85 | 92 | 82 |
| Brahmanpara | | | | | | | | | | | | 17 | 17 | 22 | 19 | 12 | | 68 |
| Burichang | 11 | 14 | 8 | 36 | 56 | 68 | | | | | | 123 | | | | 82 | | 126 |
| Comilla | 168 | 200 | 189 | 204 | 238 | 205 | 210 | 201 | 231 | 241 | 250 | 280 | 270 | 271 | 283 | 282 | | 300 |
| **Total** | **198** | **261** | **254** | **328** | **402** | **411** | **210** | **201** | **231** | **241** | **250** | **709** | **381** | **384** | **397** | **586** | **134** | **885** |
| ***Shallow Tubewells (including deep set tubewells)*** | | | | | | | | | | | | | | | | | | |
| Akhaura | | | | | | | | | | | | 24 | 42 | 53 | 76 | 130 | | 156 |
| Kasba | | 15 | 0 | 0 | 2 | 8 | | | | | | 356 | 194 | 226 | 207 | 370 | | 401 |
| Nabinagar | | 15 | 0 | 0 | 1 | 3 | | | | | | 28 | | 36 | | 172 | 173 | 128 |
| Bancharampur | | 0 | 8 | 0 | 0 | 1 | | | | | | 21 | 76 | 134 | 213 | 387 | 440 | 411 |
| Homna | | 11 | 3 | 0 | 2 | 4 | | | | | | 43 | 68 | 78 | 104 | 337 | | 407 |
| Daudkandi | | 0 | 0 | 0 | 5 | 14 | | | | | | 112 | | 82 | | 181 | | 196 |
| Muradnagar | | 8 | 4 | 1 | 2 | 3 | | | | | | 40 | | 6 | | 146 | | 106 |
| Debidwar | | 25 | 16 | 3 | 5 | 27 | | | | | | 409 | | 253 | | 352 | 428 | 393 |
| Brahmanpara | | | | | | | | | | | | 182 | 137 | 255 | 228 | 274 | | 318 |
| Burichang | | 0 | 3 | 50 | 98 | 149 | | | | | | 509 | | | | 540 | | 413 |
| Comilla | | 0 | 44 | 129 | 244 | 370 | 339 | 426 | 527 | | | | | 519 | 515 | 633 | | 513 |
| **Total** | | **74** | **78** | **183** | **359** | **579** | **339** | **426** | **527** | **0** | **0** | **1,724** | **517** | **1,642** | **1,343** | **3,522** | **1,041** | **3,442** |

Sources:
AST/CIDA (1991), BBS (for areas)
Min. Ag (1975)
MMP (1986, 89, 92)
Sharfiullah (1990)

Notes:
1. Totals are for the full thana
2. All numbers are total operating numbers
3. Old data include Brahmanpara under Burichang

## TABLE C.5.4

### Deep Setting of Shallow Tubewells

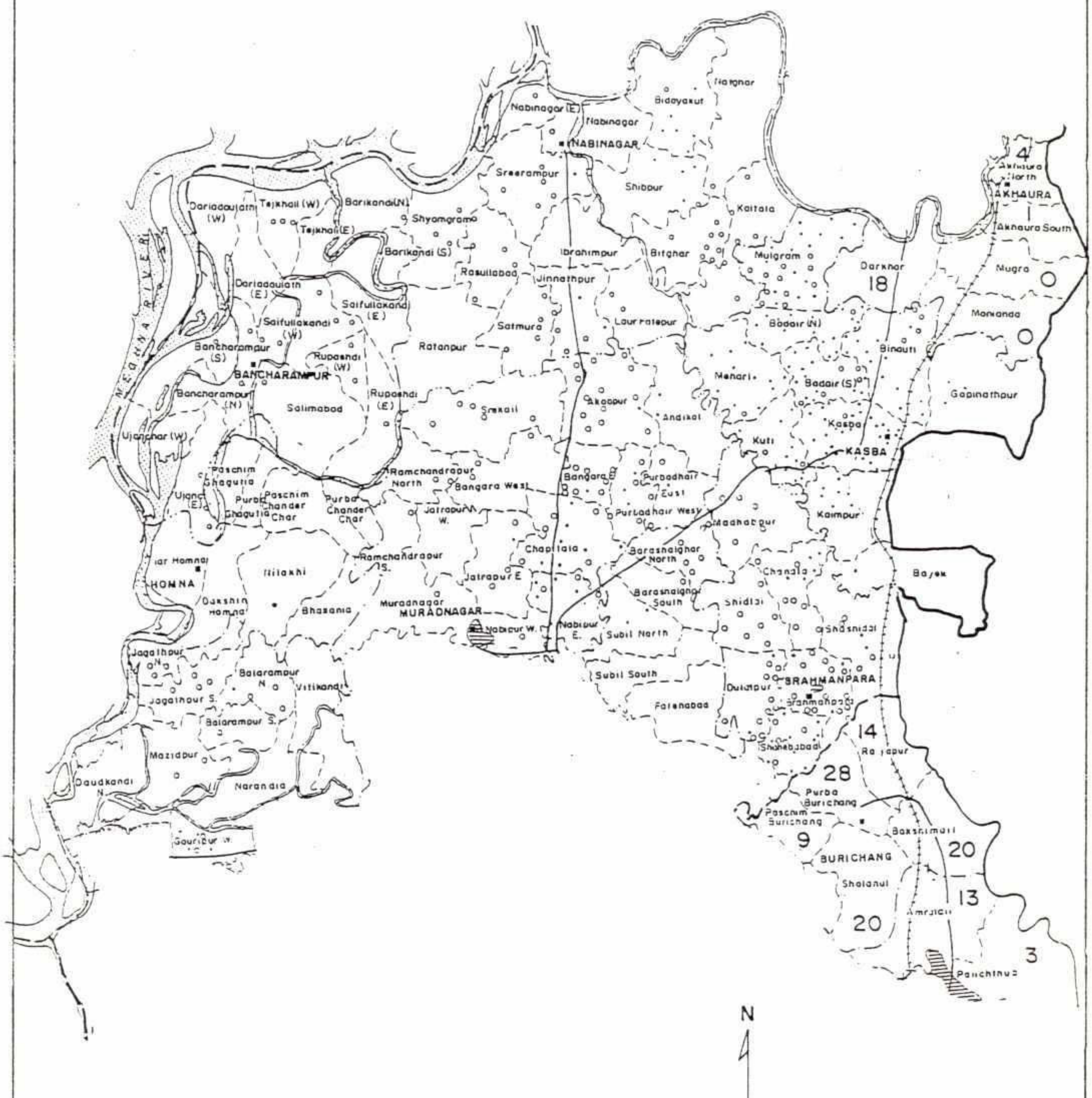
| Thana | 1987/88 | | 1988/89 | | 1990/91 | |
|---|---|---|---|---|---|---|
| | STW | DSSTW | STW | DSSTW | STW | DSSTW |
| Akhaura | 99 | 10 | 127 | 3 | 156 | 0 |
| Kasba | 289 | 1 | 364 | 4 | 401 | 0 |
| Nabinagar | 102 | 1 | 171 | 1 | 128 | 0 |
| Bancharampur | 303 | 0 | 387 | 0 | 411 | 0 |
| Homna | 208 | 5 | 322 | 5 | 407 | 0 |
| Daudkandi | 144 | 1 | 179 | 2 | 196 | 0 |
| Muradnagar | 50 | 0 | 145 | 1 | 106 | 0 |
| Debidwar | 326 | 0 | 351 | 1 | 393 | 0 |
| Brahmanpara | 216 | 0 | 255 | 19 | 318 | 0 |
| Burichang | 496 | 39 | 480 | 60 | 406 | 7 |
| Comilla | 557 | 105 | 544 | 89 | 410 | 103 |

Source : AST/CIDA (1989, 1991)

### C.5.2 Distribution of Irrigation

Figures C.5.2 to C.5.4 show the distribution of deep and shallow tubewells on the project. For the Deep Tubewell II project area it has been possible to show individual well locations, while all other data are shown as the number operating in each union (according to the AST/CIDA survey). There are particularly dense concentrations of DTWs along the piedmont areas of Comilla, Burichang, Brahmanpara and Kasba. The general concentration of DTWs in the east of the area is partly a product of the larger proportion of high and medium high land, but is also the result of a regulated supply of DTWs over the years. The distribution of shallow tubewells by union are shown both for 1987 in Figure C.5.3 and 1991 in Figure C.5.4. There is a particularly striking contrast between the piedmont area where there may be as many as a hundred STWs in a union, and the Muradnagar area where several adjoining unions contain none at all. The main reason for the anomalously low numbers of STWs is the widespread occurrence of natural gas in the top 40 metres of the aquifer. In some areas this is combined with a general shortage of screenable aquifer material in the top 60 metres. The area of low STW numbers in Burichang is probably not a constrained area, but rather is particularly favourable for surface water development, however, this may change in response to irrigation development in India.

**Figure C.5.2**
## Location of Deep Tubewells




Legend

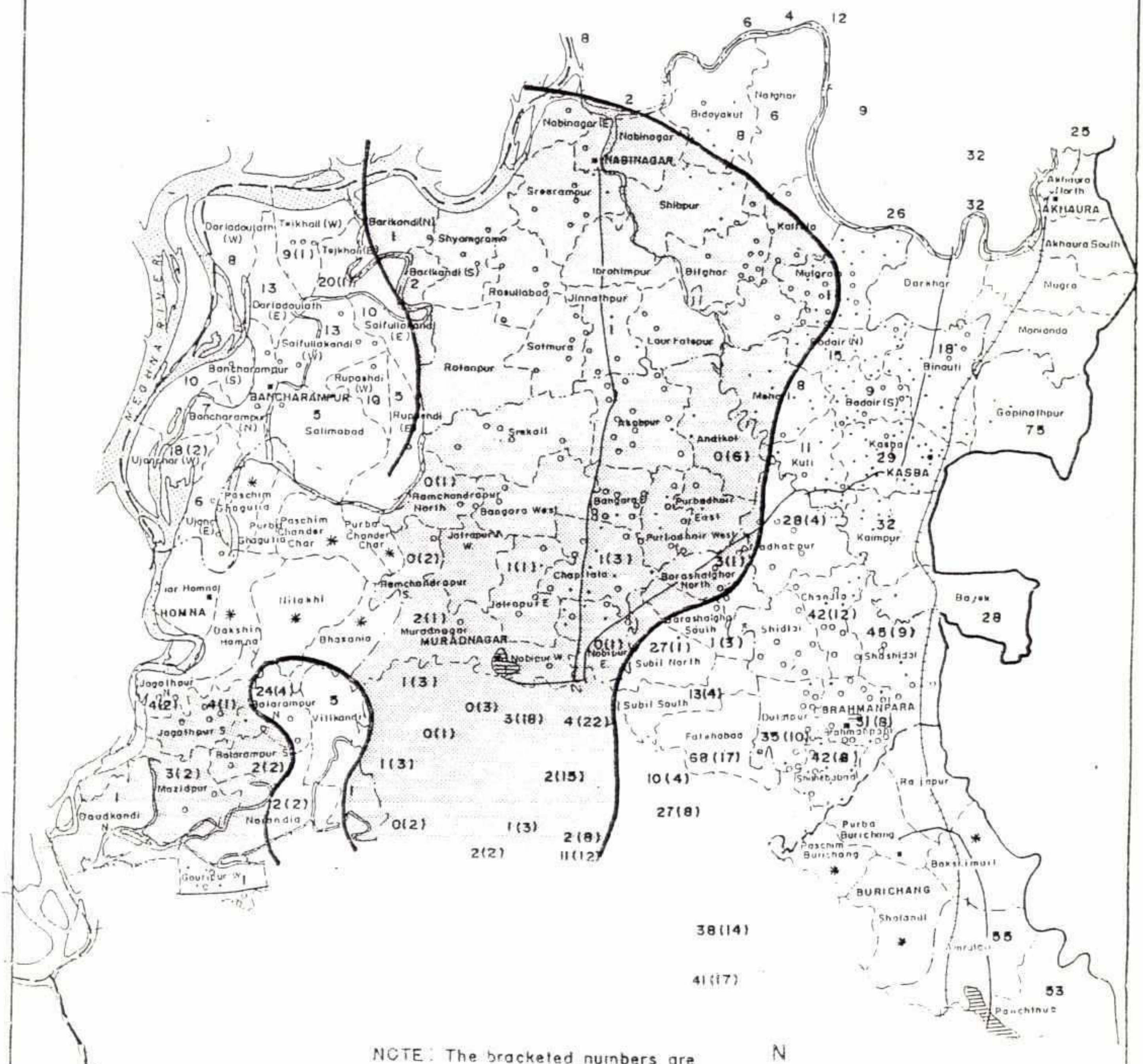
- • Local Progamme Deep Tubewell
- o IDA DTW II Project Deep Tubewell
- 14 Number of DTWS in union

Note

There are 5 commissioned DTWS in Homna thana

Source : Deep Tubewell II Project, Final Report(MMI, 1992)

Figure C.5.3
## Unionwise Distribution of Shallow Tubewells in : 1987




NOTE: The bracketed numbers are the additional numbers of STWs abandoned.

* Data not available

N

0 5 10 15 km

LEGEND

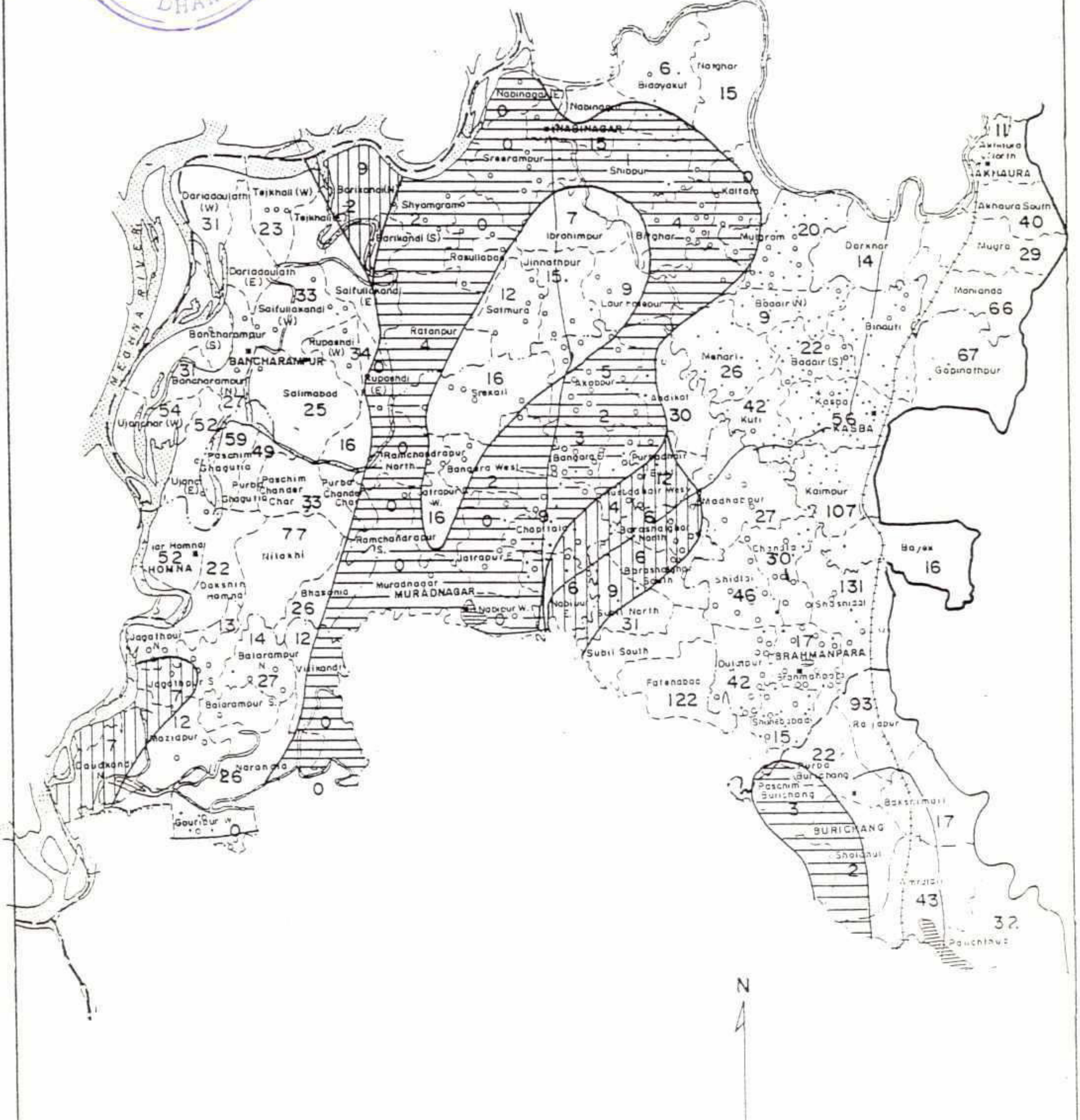
☐ Anomalously low numbers of shallow tubewells

13 Number of STWs operating

Source: BADC

Figure C.5.4

# Unionwise Distribution of Shallow Tubewells in : 1991




Legend
- • Local Progamme Deep Tubewell
- o IDA DTW II Project Deep Tubewell
- 1 Number of STWS in union
- Anomalously low number of ST Ws
- STW development almost or completely absent

0 5 10 15 km

Source : A ST/CIDA (1991)

### C.5.3 Crop and Irrigation Water Requirements

A detailed examination of the crop and irrigation water requirements by thana was carried out by MMI (1992) using the FAO computer program CROPWAT and a back analysis of the operational monitoring records of the DTW II project wells. Strictly speaking the results apply only to deep tubewell irrigation, however, in the absence of any other evidence these have been used as the basis for assessing irrigation water use by other technologies. Their estimates of irrigation requirements (i.e. that part of the irrigation water applied that goes to crop consumptive use) for Comilla are given in Table C.5.5.

**TABLE C.5.5**

**Crop and Irrigation Water Requirements at Comilla**

| | |
|---|---|
| Climate station analysed | Comilla |
| Average transplanting date (at DTWs) | 10 February |
| Effective rainfall | 285 mm |
| Deep percolation rate | 5.0 mm/d |
| Crop requirement | 509 mm |
| Irrigation Requirement | 886 mm |
| Deep Percolation | 505 mm |

Source : MMI (1992)

Irrigation requirements may vary greatly from year to year depending on the intra-seasonal rainfall. MMI (1992) showed that the net irrigation requirement (excluding deep percolation losses) varied between 387 mm in 1989 and only 95 mm in 1990.

From interviews carried out during the public participation meetings, and from the theoretical analysis presented in Appendix C.VII, it appears that STW irrigation and some LLP irrigation are associated with a different farming system which practises deliberate under-irrigation. The reason behind this that STWs and LLPs sited on khals or beels that dry towards the end of the dry season cannot maintain their full discharge throughout the irrigation season. This contrasts with deep tubewells where, by adjusting the engine speed, it is practical to maintain a more or less constant discharge. Rapidly declining discharges are an inherent characteristic of wells with suction pumps and falling water tables. It appears that STW irrigators plant HYV seeds and take advantage of the good discharge early in the season and apply full water requirement in January and February. As the water supply reduces during March and April the crops suffer slightly and grow at less than the maximum rate, but farmers hope for some rains at this time to supplement the irrigation water and carry the crop through to reasonable harvest. It is tentatively suggested that the rice yields may be a little under 3 tons per hectare if there is rain at the right time, but may fall to around 1.5 tons/ha if there is no rain. This compares with typical yields of over 4 tons/ha with full irrigation. It is quite possible that this low input - low output production system is actually an optimum economic response to the nature of STW technology; it may also be associated with different patterns of fertiliser and pesticides inputs, and warrants further investigation.

## C.6 Key Concepts for Groundwater Development

### C.6.1 Salinity Constraints

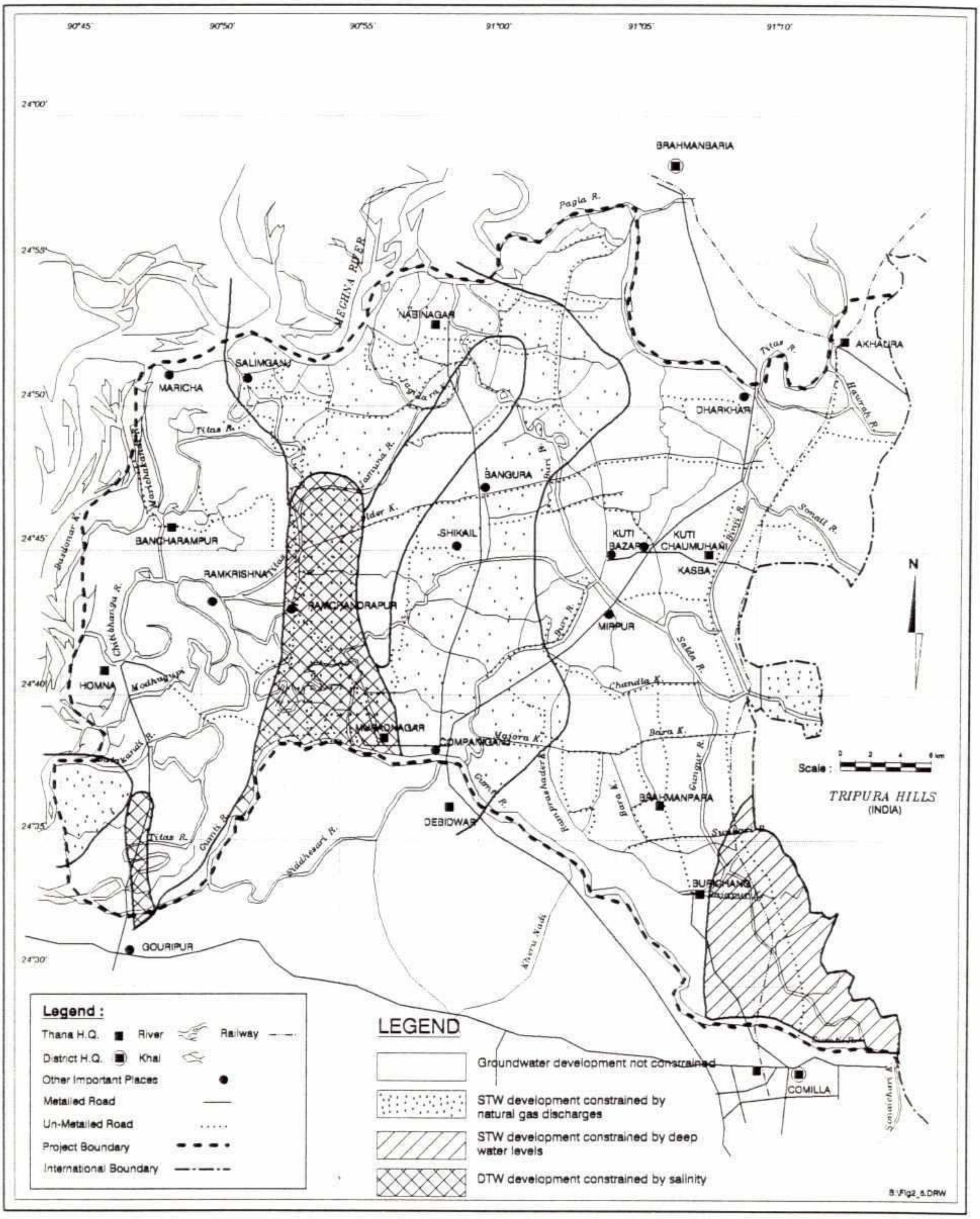
Chapter C.4 described the distribution and origin of groundwater salinity in the study area. For irrigation purposes it was shown that no impact on the yields of either rice or wheat would be expected if the irrigation water does not exceed 2,000 μS/cm, although yield reductions might be expected with certain vegetables if irrigated with water of more than 1,000 μS/cm. Long term historical precedent indicates that irrigation will continue to be dominated by rice and/or wheat. Therefore, for resource planning it is assumed that groundwater may be recommended for irrigation wherever the salinity does not, or will not, exceed 2,000 μS/cm. The shallow aquifer zones, down to about 40 metres, may exploited throughout the Gumti Phase II area. In effect, it may be said that salinity is not a constraint on suction mode tubewell development in the area. Where it is proposed, or necessary to, exploit the deeper aquifers the 2,000 μS/cm contour in Figure 4.1 should serve as a fairly reliable guide, although some caution (or optimism) should be shown when drilling within a kilometre or two of the boundary of this zone. The 2,000 μS/cm contour was used to define the area of salinity constraints in Figure C.6.1 and Table C.6.1. Where a well or test drilling encounters saline water it should be abandoned and an alternative shallow, low capacity design considered.

**TABLE C.6.1**

**Constraints on Groundwater Development**

| Thana | Gross Area (in project) ha | % of Gross Area Affected | | |
|---|---|---|---|---|
| | | STW Gas Constraint | DTW Gas Constraint | DTW Salinity Constraint |
| Akhaura | 9,489 | 0% | 0% | 0% |
| Kasba | 20,732 | 10% | 0% | 0% |
| Nabinagar | 32,007 | 54% | 5% | 1% |
| Bancharampur | 21,595 | 9% | 0% | 3% |
| Homna | 17,947 | 4% | 0% | 4% |
| Daudkandi | 12,025 | 31% | 5% | 7% |
| Muradnagar | 24,541 | 76% | 5% | 22% |
| Debidwar | 7,519 | 38% | 5% | 0% |
| Brahmanpara | 12,851 | 0% | 0% | 0% |
| Burichang | 9,864 | 0% | 0% | 0% |
| Comilla | 4,648 | 0% | 0% | 0% |

# Figure C.6.1
## Groundwater Development Constraints



The comments above apply to short to medium term pumping, perhaps for a period of years. However, it should be recognised that there is a possibility that large scale exploitation of groundwater from the shallow aquifer, where the deeper aquifer is saline, might promote the upward migration (upconing) of saline water. Because highly saline water only appears to be present where there is a thick lower aquitard, it is considered that this effect will be minimal, or occur at such a slow rate that the saline water is so diluted that it does not limit the use of the water for irrigation. These issues are explored further through the use of various models in section 7.3. Lateral migration of saline groundwater in the main aquifer is a possibility if there is intensive abstraction from this deeper zone in the adjoining areas (actually it is likely to be divided between the shallow and deep zones). But again the possibility of this effect being significant is very unlikely. Although it has not been 'measured' the saline interface in the main aquifer is likely to be so diffuse that sudden failure of any well would not occur. Nevertheless, it is important the salinity of wells near to the saline areas should be monitored regularly.

Even though the saline groundwater is a finite body of connate water, thousands of years old, it is unlikely that it would ever be economically viable to 'clean up' the aquifer. This view is most strongly supported by the probability of being able to extract the desired quantities of groundwater from shallow aquifers at the same locations. Eventually the aquifer system would be 'cleaned up' by the flushing action of natural groundwater flow regime, but this is likely to take thousands of years. Nonetheless, if problems of saline upconing are encountered, the use of scavenger wells[1] could be a viable option to control the problem, or simply to allow the use of higher capacity pumps in the shallow zone.

### C.6.2 Natural Gas Constraints

Discharges of natural gas to tubewells are very common, especially in Zones C and D. Although it is widely recognised by farmers to be a constraint on irrigation, apparently none of the studies conducted before 1992 identified the problem (here, or apparently in other areas). Further, the conventional MPO style assessments of groundwater potential do not recognise gas as a constraint. Consequently the project has conducted a special survey of the occurrence of gas in irrigation wells, and is described in full in Appendix C.I. A summary of the findings is given below.

Gas discharges have been noted from DTWs, STWs and hand tubewells for drinking water. Gas is observed coming out of solution during the operation of wells. Many times the gas may be ignited, indicating the presence of methane. Chemical analyses indicate that significant concentrations of dissolved carbon dioxide are present in the water, and traces of hydrogen sulphide are also noted from their smell. The redox conditions and the abundance of organic matter probably account for the production of gases in the shallow groundwater environment, although leakage from deep strata in the Bakhrabad Anticline[2] is an alternative source for the gas. Drilling contractors report striking larger pockets of gas during drilling, which sometimes lead to abandonment of the hole, and are a potential danger to the workers. Drillers report that gas problems occur predominantly in the shallow aquifer. There are no records of gas discharges being an actual safety hazard at operating tubewells.

---

1 A double pumping system, where a lower well or pump extracts salt water and discharges to waste.

2 A commercial gas field.

The locations of deep tubewells with reported gas problems and the documentary evidence are given in Appendix C.1. Problem wells are largely restricted to Zone C. In the majority of cases gas is a nuisance for DTWs, and may reduce the working life of pumpsets by promoting corrosion, but only a very small proportion of 'problem wells' cannot be operated usefully.

It is more difficult to quantify the constraint on STWs. However, there is no doubt that high speed, surface mounted suction pumps are inherently more susceptible to interference from gas discharges, which cause loss of suction. Interviews with BADC, BRDB and DAE officials, STW drillers, pump mechanics and farmers indicate serious problems in some areas. Indirect evidence is provided by the intensity of STW irrigation (see Figures C.5.3 and C.5.4). It is seen that these areas closely coincide. Also the BADC STW inventory in 1987 showed that the areas of lowest STW intensity also had the highest rates of abandonment[3], indicating that STW irrigation was desired but found not feasible. The areas where STW development is constrained are shown in Figure C.6.1 and Table C.6.1.

Gas in HTWs is extremely common, supporting the shallow origin of the gas, and as with DTWs is a nuisance but does not prevent the operation of wells. This is presumably due to the very slow operating speed of pump. Local people are generally aware where gas from hand tubewells can be ignited, these areas, if mapped, should be the same as those where STWs do not operate effectively, and offer a rapid reconnaissance method for examining other areas.

The distribution of gas occurrences in groundwater closely resembles that of salinity distribution in the main aquifer. This is probably explained by the high organic matter content of the upper part of the Chandina Formation and perhaps especially so in the estuarine silts. This unfortunate combination locally results in areas where gas makes STWs impractical in the upper aquifer and salinity makes DTWs impractical in the lower aquifer.

### C.6.3 Aquifer Configuration and Water Levels

Over most of the project area, the (exploited) aquifers may be treated as a single system in which the variation of piezometric level with depth is less than about a metre. However, a thick lower aquitard is present in large parts of Muradnagar, Debidwar and Daudkandi, and in small parts of Nabinagar and Kasba. In these certain circumstances it is possible to develop irrigation wells either above or below this aquitard, and in some cases in appears that some DTWs have been screened both above and below. Under comparable conditions in Kishorganj District, it has been shown (MMI, 1992) that a water level difference of as much as 9 metres may develop during the dry season, such that STWs may operate with ease in the shallow aquifer but are completely inoperable in the deep aquifer. These large head differences develop for a number of reasons:

- the proportion of abstraction taken from each aquifer,
- the shallow aquifer is unconfined while the lower aquifer is (semi-)confined.
- deep percolation losses from all types of irrigation recharge the shallow zone, where water levels respond rapidly.

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[3] The data are reported by union, and reasons for abandonment are not given.

Hence the resource potentials (by technology) are a function of not only the aquifer conditions but also of the modes of development. Unfortunately, there have been no determinations of the permeability of the lower aquitard and the present monitoring system and/or the low abstractions from each aquifer make it impossible to say with certainty that the same effects will be observed in the Gumti area, however, it is expected that they will be locally significant if groundwater abstraction is intensified. The possible consequences of multi-layered aquifers are examined further in section C.7.3.

### C.6.4 Choice of Tubewell Technology

Groundwater abstraction technologies in Bangladesh may be usefully classified into four groups on the basis of two criteria - whether the pumps are suction mode (surface mounted) or force mode (down the well), and whether they are mechanically or manually powered. As shown in Chapter C.5 manual pumps are of little importance for irrigation in the study, but on the other hand they probably account for well over 90% of safe drinking water supplies. The operation of suction mode wells with surface mounted pumps is limited to water level depths of between 5 and 7 metres, depending on discharge and aquifer conditions. Where they work, suction mode wells are always cheaper to construct that their force mode equivalent, and are therefore widely preferred.

Where water levels exceed these depths, either force mode wells must be developed or the suction pump must be placed in an excavation. In northwest Bangladesh, suction pumps have been set as deep as six metres, however, in most of the Gumti area it is unlikely to be practical to set pumps deeper than an about 2 metres. Practically, the deep setting option only applies to mechanically powered irrigation pumps; for drinking water supplies, more expensive piston pumps (the 'Tara') replace the popular UNICEF Nr 6 pump, with an associated increase in cost of from $90 to about $230 for a well that can serve up to about a hundred people. For irrigation purposes, force mode tubewells have been virtually synonymous with the BADC 2 cusec deep tubewell. However, with the current plans for privatisation there is likely to be a major shift towards lower capacity wells, the use of cheaper well components, shorter screen lengths, and lower quality but cheaper pumps and engines. A particular uncertainty in areas such as the Comilla region is whether force mode wells would continue to be screened in the deeper medium to coarse sand aquifer, or whether they will be screened in the shallow fine to medium sand aquifer normally exploited by shallow wells. This would reduce capital costs, but would probably increase drawdowns and, in some areas, gas problems and clogging of screens by fines. The range of force mode tubewell design options are set out in Figure C.6.2.

Where gas discharges occur, either the efficiency of shallow tubewell pumps is severely impaired or they do not work at all. The best solution in these areas would be to use force mode wells, either in the deeper parts of the aquifer where there is less gas, or to construct shallow, low capacity force mode tubewells in the same aquifer that would otherwise normally be exploited by STWs. It has been suggested[4] that shallow tubewells might be overcome the gas problem if they were constructed with a separate suction pipe suspended inside a larger diameter well casing. In fact, in this case the well itself would be basically the same as for a force mode well, and as such it be simple and convenient to test this idea under the same programme as a force mode demonstration. However, the increased capital cost of such a STW might negate the fundamental advantage of the technology - its extremely low initial cost.

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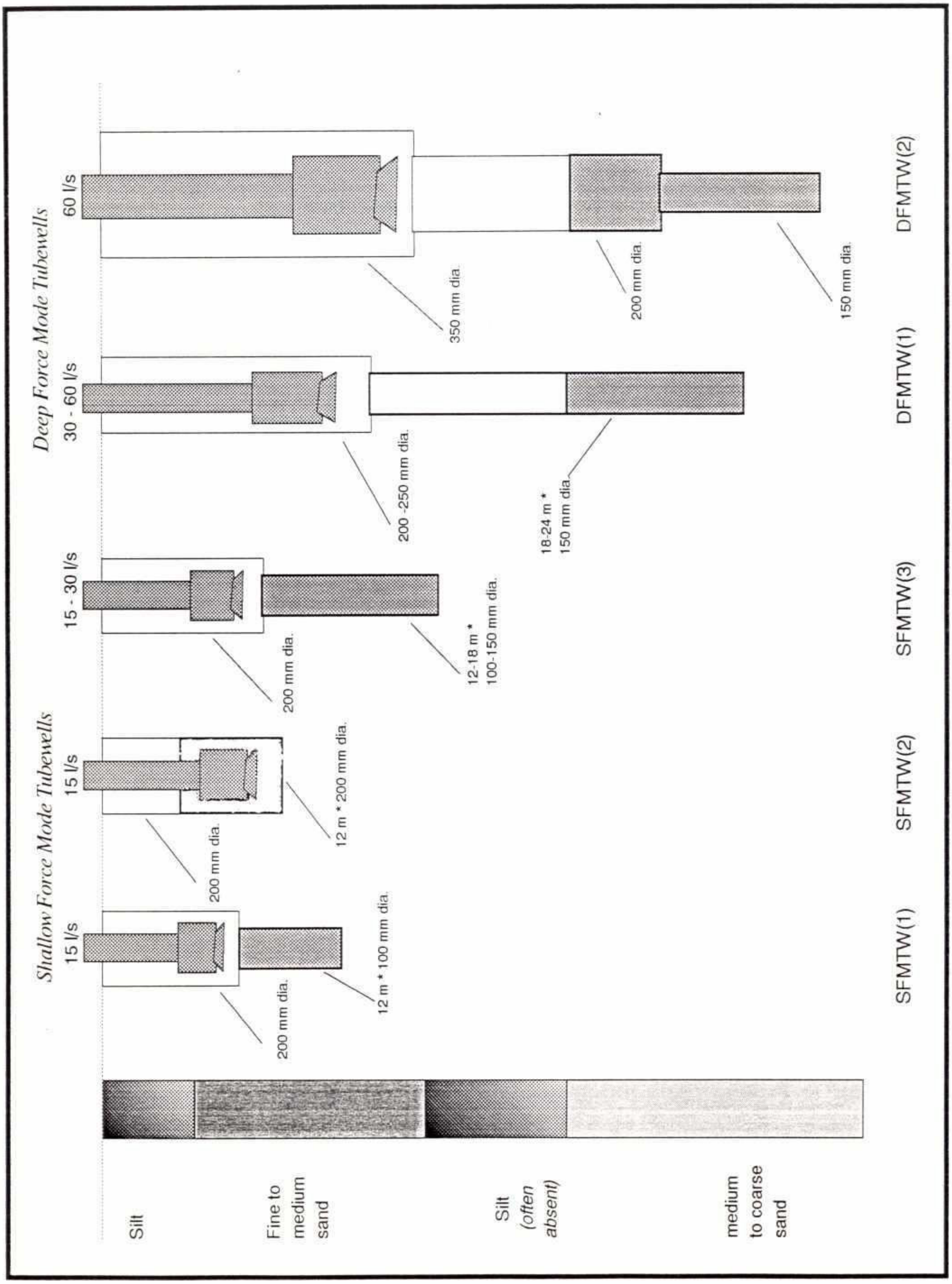
[4] D. Gisselquist, personal communication to project consultants.

**Figure C.6.2**

## Force Mode Tubewell Design Options



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Where salinity problems occur, the first alternative for groundwater irrigation is to exploit the shallow aquifer, and preferably the upper part of it. Most of the saline areas are also constrained by gas in the upper aquifer, and hence shallow force mode tubewells (SFMTWs) or manual tubewells will be required. The SFMTW has not yet been demonstrated in the gas constrained areas. Gas and salinity may both promote corrosion of well and pump components (see also Figure 4.7) and hence the use of resistant materials such as PVC or fibre glass (or stainless steel) is to be preferred. In any case, plastics would almost certainly be preferred on economic grounds. The typical design of a 15 l/s SFMTW would probably include a single diameter (either 150 or 200mm) string of casing and screen. The screen would best be constructed of PVC, but either with a smaller slot size than is conventionally used on DTWs, or perhaps with geotextile type screen (equivalent to brass STW screen). Blank casing could be of either PVC or steel. The screen diameter mentioned above is larger than needed from a consideration of screen entrance velocities, but in order to keep the screen depth to a minimum it might be better to position the pump intake in the screened section or in an additional section of blank pipe below the screen. The pump could be either a vertical turbine or an electric submersible[5].

### C.6.5 Influence of Surface Water Irrigation

There is a tendency in some quarters to regard minor irrigation as a choice between surface water and groundwater. While this may be a legitimate choice when siting an individual pump, on a regional scale the two should be seen as complimentary. When surface waters are delivered to dry land to irrigate rice, some of this water will percolate to the aquifer. This occurs at a time when natural recharge by infiltration through the soil zone would otherwise be minimal. This recharge reduces the lowering of the water table that would occur if irrigation were provided from groundwater alone. Thus, the more surface water irrigation provided in an area, the greater is the groundwater potential.

Unfortunately it is particularly difficult to obtain accurate estimates of water use from LLP schemes. Deep percolation losses must therefore be assumed to be related to percolation from tubewell irrigation in the same area, which has been analysed by MMI (1992). Nevertheless it is considered that deep percolation losses from LLP irrigation are lower than for DTW irrigation because of lower water applications and possibly greater run-off and interflow, and in the analyses in Chapter C.7 percolation losses from LLP irrigation were arbitrarily reduced by two thirds. In some areas (e.g. Nabinagar) deep percolation from LLP irrigation probably exceeds the total withdrawal by tubewells. On average, losses from LLP irrigation would be in the order of one third of the crop requirement.

If, however, surface water irrigation is reduced, there would be an adverse effect on the groundwater resources. End of dry season groundwater levels would be deeper than at present. This is a particularly serious concern along the upper reaches of the Gumti river, where it is understood that the dry season flows from India may be reduced in the foreseeable future.



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[5] If an electric submersible pump is installed below the well screen it would be necessary to add a pump shroud to ensure cooling of the motor.

## C.7 Groundwater Development Potential

### C.7.1 Methodology for Evaluating Groundwater Development Potential

Section C.6 gave a qualitative presentation of the various constraints influencing the potential development of groundwater. In this chapter, these results are brought together to give quantitative estimates of the scope for further expansion of groundwater irrigation in each thana and by each mode. The methodology for the evaluation of the potential under existing conditions is set out below:

(i) The starting points for the assessment are the maximum infiltration of water at the ground surface, the existing groundwater abstraction and the current coverage of irrigation. The maximum infiltration through the soil zone, or potential recharge, is the fundamental limiting resource. The potential recharge figures determined by SERS, which are basically a refinement of the National Water Plan Phase II estimates, have been used. This figure represents the ultimate limit for groundwater development on an annually renewable basis, i.e. without inducing either a progressive (over years) or permanent[1] lowering of groundwater levels. Estimates of irrigated area are taken from the AST/CIDA (1991) survey (Appendix C.II), and groundwater use from MMI (1992).

(ii) It has been assumed that 90% of the cultivable area is the maximum that might ever be irrigated (in fact it is probably less, but 80% is already irrigated in Akhaura). The first step is to decide whether the potential recharge is sufficient to irrigate the remaining un-irrigated land. Unit irrigation requirements by thana were determined by MMI (1992), and hence allows the volume of irrigation water to be calculated. The residual potential is simply the total potential recharge minus the current (net) abstraction. This indicates either that recharge is in excess of agricultural requirements, or what percentage of the remaining land might be irrigated. It follows for the potentials for each mode of groundwater abstraction to be evaluated.

(iii) The key to evaluating (unconstrained) potential by mode is the depth - storage curve for each thana, which determines the point (or range) of transition from suction mode to force mode pumping. This becomes complicated in the areas with a multi-layered aquifer configuration, where potentials by mode are dependent on the proportion of abstraction from each aquifer. However, it is reasonable to assume that suction mode wells will be developed first, and then take account of the impact of pumping from deeper aquifers later (if it is required at all). Ironically, the consideration given to the double aquifer condition in the Inception and First Progress reports is now recognised to be less significant than previously thought precisely because the areas where the hydraulic separation of the upper and lower aquifers is greatest are also the areas where the salinity constraints on the lower aquifer are greatest.

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[1] Also, this is not the same as 'mining', for sustainable development of groundwater in excess of the potential recharge (as defined by the MPO) is possible by producing a large cone of depression which reaches a state of equilibrium by intercepting major rivers and inducing additional recharge there from. This situation is common with municipal and industrial abstractions from major cities, such as Dhaka. This mode of development is excluded here.

For the purposes of regional planning it is necessary to define limiting water levels for suction mode wells. The limiting water table depth for suction mode development is defined here as that at which the nominal discharge of STWs and DSSTWs is reduced by two thirds to 5 l/s (0.18 cusec). Details of the calculation scheme are given in Appendix C.VII. Assuming an average permeability of 20 m/d. the limiting water table depth for STWs is about 5.5 metres. For DSSTWs it is assumed that pits will be unlined and of an average depth of 2 metres, and are therefore limited to water table depths of about 7.5 metres. The limiting water table (or rather piezometric) depth for force mode tubewells is debatable[2], but in reality is unlikely to be of significance in the study area. A limit of 20 metres has been assumed. A limiting upper water table depth must also be defined for the determining the volume of water that may be released from storage during the irrigation season. The beginning of the irrigation season is taken here as mid to late January. Fortunately, although the peaks and troughs of the groundwater hydrographs vary widely, the January levels vary little from year to year (Chapter C.3).

The adopted correlation between lithology and specific was taken as the Deep Tubewell II (MMI, 1992) revision of the MPO (1987) estimates. The specific yield profiles, in one metre intervals, were taken from analysis BADC DTW records (Appendix C.IV), except for Akhaura and Comilla where MPO data were used. For Homna, where only three records were available, the average of Muradnagar, Daudkandi and Bancharampur profiles was used. The DTW lithological records are referenced to the average land elevation of the thana. Thus for unconstrained development the potentials are simply the volumes of water released between the mid-January water level and 5.5, 7.5 and 20 metres for STWs, DSSTWs and DTWs respectively. Potentially irrigated areas are calculated by dividing these volumes by the appropriate water requirement. The results and methodology of the depth storage - analysis are shown in Table C.7.1.

(iv) First the areas where specific modes cannot operate (and hence have zero potential) are defined. These are defined as:

- where gas prevents operation of STWs and DSSTWs;
- where the main or deep aquifer is too saline to be used by DTWs;
- where water levels are too deep for STWs and DSSTWs to operate;
- where the shallow and deep aquifers have significantly different water levels during the irrigation season.

(v) Natural gas discharges have been concluded to be a negligible constraint on FMTW development, although, a minor constraint of 5% was applied to DTW development in certain thanas where problems have been encountered. Natural gas is a significant constraint on STWs and DSSTWs; and salinity is a locally serious constraint on DTW development. The effects of these constraints are incorporated into the evaluation in two ways. First, the unconstrained potentials by mode (as a volume of water) are reduced in direct proportion to the area affected. However, since the potential recharge is often in excess of the irrigation requirements, it is also necessary to reduce the area of additional potentially irrigated land (groundwater transfer not being a serious option).

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[2] Being affected by such factors as maintaining straightness and verticality of pump chambers.

## TABLE C.7.1

### Unconstrained Groundwater Potential : Depth - Storage Analysis

| Thana | Kasba | Nabinagar | Bancharampur | Homna | Daudkandi | Muradnagar | Debidwar | Brahmanpara | Burichang |
|---|---|---|---|---|---|---|---|---|---|
| Total Area (ha) | 20,732 | 32,007 | 21,595 | 17,947 | 12,025 | 24,541 | 7,519 | 12,892 | 9,864 |
| Cultivable Area | 18,245 | 28,166 | 19,435 | 15,273 | 10,341 | 21,350 | 6,617 | 9,279 | 7,238 |
| Potential Recharge (mm) | 613 | 673 | 431 | 540 | 539 | 708 | 566 | 496 | 495 |
| Av. Ground Elevation (m PWD) | 4.8 | 4.0 | 3.5 | 3.5 | 3.0 | 4.0 | 4.0 | 5.0 | 5.5 |
| January Water Level (m PWD) | 4.4 | 1.5 | 2.1 | 2.3 | 2.0 | 2.3 | 3.5 | 4.5 | 3.77 |
| Depth to water (m bgl) | 0.4 | 2.5 | 1.4 | 1.2 | 1.0 | 1.7 | 0.5 | 0.5 | 1.7 |
| *Integrated Specific Yields* | | | | | | | | | |
| Sp. yld to Jan. WL (integer) | | 0.020 | 0.035 | 0.030 | | 0.024 | | | |
| Sp. yld to Jan. WL (integer+1) | 0.020 | 0.021 | 0.042 | 0.036 | 0.041 | 0.024 | 0.020 | 0.021 | 0.022 |
| Sp. yld to Jan. water level | 0.020 | 0.021 | 0.039 | 0.033 | 0.041 | 0.024 | 0.020 | 0.021 | 0.022 |
| Specific yield to 5 m | 0.028 | 0.032 | 0.053 | 0.046 | 0.051 | 0.033 | 0.024 | 0.027 | 0.024 |
| Specific yield to 6 m | 0.030 | 0.036 | 0.056 | 0.048 | 0.053 | 0.035 | 0.024 | 0.029 | 0.025 |
| Specific yield to 7 m | 0.032 | 0.040 | 0.059 | 0.051 | 0.055 | 0.038 | 0.025 | 0.032 | 0.028 |
| Specific yield to 8 m | 0.033 | 0.043 | 0.062 | 0.053 | 0.057 | 0.041 | 0.025 | 0.034 | 0.030 |
| Specific yield to 20 m | 0.049 | 0.062 | 0.076 | 0.070 | 0.074 | 0.060 | 0.041 | 0.051 | 0.048 |
| Vol of water released to Jan WL | 8 | 51 | 54 | 38 | 40 | 42 | 11 | 11 | 38 |
| Vol of water released to 5.5m | 160 | 187 | 300 | 258 | 286 | 187 | 132 | 154 | 135 |
| Vol of water released to 7.5m | 244 | 311 | 454 | 390 | 420 | 296 | 188 | 248 | 218 |
| Vol of water released to 20m | 980 | 1240 | 1520 | 1400 | 1480 | 1200 | 820 | 1020 | 960 |
| Unconstrained STW Potential | 152 | 136 | 246 | 220 | 246 | 145 | 121 | 144 | 97 |
| Unconstrained DSSTW Potential | 236 | 260 | 400 | 352 | 380 | 254 | 177 | 237 | 179 |
| Unconstrained DTW Potential | 613 | 673 | 431 | 540 | 539 | 708 | 566 | 496 | 495 |
| DTW Potential as % of recharge | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| *If 100%, what is deepest WL* | | | | | | | | | |
| WL to extract 100% of recharge | 15 | 13 | 7 | 9.7 | 9 | 13 | 16 | 12 | 13 |
| Integrated Specific yield at depth: | 0.041 | 0.053 | 0.059 | 0.056 | 0.058 | 0.052 | 0.035 | 0.040 | 0.039 |
| Depth of water released (mm): | 615 | 689 | 413 | 545 | 522 | 676 | 560 | 480 | 507 |
| Proportion of recharge withdrawn | 100.4% | 102.4% | 95.9% | 100.8% | 96.9% | 95.5% | 98.9% | 96.7% | 102.4% |

Notes: 1. Because of insufficient lithological data, the specific yields used for Homna are the average of Daudkandi, Bancharampur and Muradnagar
2. See Appendix IV for lithological and specific yield profiles

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Thus groundwater development potential is defined in a number of ways, and are technology dependent. These potentials are first derived for the unconstrained conditions, and then reduction factors are applied to take account of the various constraints.

(vi) The positive impact of surface water irrigation may be incorporated in the analysis by estimating the volume of percolation losses from LLP and traditional methods between mid-January and the end of april. This volume is then added to the unconstrained potential for each tubewell technology. It has been assumed, for the purposes of assessing groundwater potential, that surface water irrigation will remain at its 1991 level. This is not a statement of project policy, merely a planning convenience, and it should be noted that any increase in surface water irrigation will also increase the groundwater potential.

(vii) For thanas where various combinations of abstractions from partially hydraulically separated aquifers are possible, the evaluations have been carried out on an individual basis incorporating the SCTM model results.

### C.7.2 Groundwater Resource Potential under Existing Conditions

Table C.7.2 gives a comparison of the constrained and unconstrained resource potentials estimated by the present study and previous studies. The unconstrained potentials have increased chronologically partly because of the inclusion of the effects of surface water irrigation and partly because of the updated lithological data. According to the MPO Phase II estimates, current abstraction has exceeded the STW potential in most thanas, while according to project estimates it is only clearly exceeded in Burichang (which has deep water levels and a record of deep setting), and has been equalled in Comilla, Brahmanpara (where there is a history of deep setting) and Muradnagar (where STWs are severely constrained by gas). Inclusion of surface water irrigation in the analysis is the main reason for the change in resource estimation in Akhaura, Nabinagar, Homna and Daudkandi. Previous estimates indicated that the DSSTW potentials has been exceeded in some thanas, whereas the current estimates indicate that all thanas have additional DSSTW potential - which is consistent with the evidence given in Chapters C.3 and C.5.

Tables C.7.3 to C.7.5 describe the probable impact of increased groundwater irrigation, **without project intervention**, which has been assessed on the assumption that it would occur in three phases:

- additional STWs up to suction limits (without deep setting)
- additional STWs and DSSTWs up to suction limits
- development by suction mode wells first, followed by force mode wells where land resources remain un-irrigated

**TABLE C.7.2**

**Comparison of Current Abstraction with Resource Estimates**

| Thana | Net Groundwater Abstraction mm/yr | MPO Phase II Estimates STW Potential mm/yr | DSSTW Potential mm/yr | DTW(1) Potential mm/yr | SERS Potentials DSSTW Potential mm/yr | DTW(1) Potential mm/yr | Unconstrained Potentials *(Present Study)* STW Potential mm/yr | DSSTW Potential mm/yr | Constrained Potentials *(inc. SW irrigation)* STW Potential mm/yr | DSSTW Potential mm/yr |
|---|---|---|---|---|---|---|---|---|---|---|
| Akhaura | 84 | * 74 | 242 | 738 | 190 | 738 | *nd* | *nd* | 177 | 296 |
| Kasba | 122 | * 101 | 183 | 506 | * 106 | 613 | 152 | 236 | 183 | 259 |
| Nabinagar | 19 | * 16 | 59 | 288 | 126 | 673 | 136 | 260 | 120 | 177 |
| Bancharampur (1) | 49 | 93 | 171 | 431 | 171 | 431 | 246 | 400 | 273 | 413 |
| | | | | | | | | | | |
| Homna | 79 | * 78 | 150 | 507 | 178 | 540 | 220 | 352 | 266 | 392 |
| Daudkandi | 59 | * 42 | 85 | 364 | 159 | 539 | 246 | 380 | 261 | 353 |
| Muradnagar | 44 | 65 | 109 | 425 | 142 | 708 | 145 | 254 | * 43 | 69 |
| Debidwar | 62 | 84 | 147 | 566 | 113 | 566 | 121 | 177 | 111 | 146 |
| Brahmanpara | 166 | * 132 | 248 | 597 | * 116 | 496 | * 144 | 237 | * 165 | 258 |
| Burichang | 190 | * 73 | * 134 | 482 | * 134 | 495 | * 97 | * 179 | * 122 | 204 |
| Comilla | 179 | * 86 | * 164 | 486 | * 157 | 493 | *nd* | *nd* | * 170 | 210 |

Notes :

1. * indicates current abstraction greater than estimated potential
2. The constrained potentials for the present study include the additional (dry season) recharge derived from surface water irrigation
3. 'nd' indicates 'not determined'
4. Quantities of water are expressed as a depth of water averaged over the gross area of the thana (inside the the project)
5. SERS - South East Regional Study (FAP:5)

## TABLE C.7.3

### Analysis of Future Groundwater Development by STWs Only

| Thana | Total Area Irrigated ha | Cultivable Area Irrigated % | Suction Mode ha | Force Mode ha | Net GW Abstn. mm | % of Constrained Potential Recharge | *Water table at full development* Est. SWL m | Int. Specific Yield | Vol. Released mm |
|---|---|---|---|---|---|---|---|---|---|
| Akhaura | 5 753 | 90% | 1 668 | 567 | 120 | 14% | | - | - |
| Kasba | 11 914 | 65% | 5 143 | 2 240 | 183 | 28% | 5.0 | 0.028 | 184 |
| Nabinagar | 16 855 | 60% | 7 168 | 535 | 120 | 16% | 2.4 | 0.020 | 124 |
| Bancharampur | 17 492 | 90% | 12 272 | 230 | 272 | 58% | 5.1 | 0.053 | 272 |
| Homna | 13 468 | 88% | 10 136 | 20 | 266 | 46% | 5.3 | 0.046 | 263 |
| Daudkandi | 9 307 | 90% | 4 008 | 235 | 166 | 28% | 1.9 | 0.041 | 169 |
| Muradnagar(2) | 6 055 | 28% | 857 | 1 385 | 44 | 8% | 2.0 | 0.024 | 44 |
| Debidwar | 2 632 | 40% | 1 567 | 141 | 111 | 19% | 3.0 | 0.020 | 108 |
| Brahmanpara | 5 148 | 56% | 2 389 | 1 808 | 167 | 32% | 5.5 | 0.028 | 164 |
| Burichang | 4 519 | 62% | 828 | 2 840 | 190 | 37% | 7.2 | 0.028 | 188 |
| Comilla | 2 483 | 69% | 729 | 898 | 179 | 33% | | - | - |
| Total / Average | **95 625** | **67%** | **46 764** | **10 899** | **165** | **29%** | **4.2** | **0.026** | **138** |

## TABLE C.7.4

### Analysis of Future Groundwater Development by STWs and DSSTWs

| Thana | Total Area Irrigated ha | Cultivable Area Irrigated % | Suction Mode ha | Force Mode ha | Net GW Abstn. mm | % of Constrained Potential Recharge | *Water table at full development* Est. SWL m | Int. Specific Yield | Vol. Released mm |
|---|---|---|---|---|---|---|---|---|---|
| Akhaura | 5 753 | 90% | 1 668 | 567 | - | - | | - | - |
| Kasba | 14 947 | 82% | 8 176 | 2 240 | 259 | 39% | 6.9 | 0.031 | 258 |
| Nabinagar | 20 487 | 73% | 10 800 | 535 | 177 | 24% | 3.9 | 0.026 | 177 |
| Bancharampur | 17 492 | 90% | 12 272 | 230 | - | - | | - | - |
| Homna | 13 746 | 90% | 10 414 | 20 | 273 | 48% | 5.4 | 0.047 | 273 |
| Daudkandi | 9 307 | 90% | 4 008 | 235 | - | - | | - | - |
| Muradnagar(2) | 7 343 | 34% | 2 145 | 1 385 | 69 | 13% | 3.0 | 0.024 | 68 |
| Debidwar | 3 163 | 48% | 2 098 | 141 | 146 | 25% | 4.0 | 0.024 | 144 |
| Brahmanpara | 7 459 | 81% | 4 701 | 1 808 | 258 | 50% | 7.6 | 0.032 | 254 |
| Burichang | 4 794 | 66% | 1 103 | 2 840 | 204 | 39% | 7.9 | 0.028 | 208 |
| Comilla | 2 773 | 77% | 1 019 | 898 | 210 | 38% | | | 53 |
| Total / Average | **107 264** | **75%** | **58 403** | **10 899** | **145** | **25%** | **5.5** | **0.021** | **131** |

## TABLE C.7.5

### Analysis of Future Groundwater Development by Suction and Force Mode Wells

| Thana | Total Area Irrigated ha | Cultivable Area Irrigated % | Suction Mode ha | Force Mode ha | Net GW Abstn. mm | % of Constrained Potential Recharge | Water table at full development Est. SWL m | Int. Specific Yield | Vol. Released mm |
|---|---|---|---|---|---|---|---|---|---|
| Akhaura | 5 753 | 90% | 1 668 | 567 | 567 | - | | - | - |
| Kasba | 16 420 | 90% | 8 176 | 3 713 | 295 | 44% | 7.9 | 0.032 | 297 |
| Nabinagar | 25 349 | 90% | 10 800 | 5 397 | 253 | 34% | 5.5 | 0.032 | 252 |
| Bancharampur | 17 492 | 90% | 12 272 | 230 | 230 | - | | | - |
| Homna | 13 746 | 90% | 10 414 | 20 | 20 | - | | - | - |
| Daudkandi | 9 307 | 90% | 4 008 | 235 | 235 | - | | - | - |
| Muradnagar(2) | 19 215 | 90% | 2 145 | 13 257 | 301 | 55% | 7.8 | 0.039 | 300 |
| Debidwar | 5 955 | 90% | 2 098 | 2 933 | 328 | 55% | 10.0 | 0.028 | 328 |
| Brahmanpara | 8 324 | 90% | 4 701 | 2 673 | 293 | 57% | 8.3 | 0.034 | 293 |
| Burichang | 6 514 | 90% | 1 103 | 4 561 | 293 | 56% | 9.5 | 0.032 | 291 |
| Comilla | 3 238 | 90% | 1 019 | 1 363 | 261 | 48% | | - | - |
| Total / Average | **131 314** | **90%** | **58 403** | **34 950** | **280** | **32%** | **8.2** | **0.020** | **160** |

The principal conclusion of this analysis is that in all thanas **it is possible to irrigate all remaining land from groundwater** by some method without exceeding (a maximum of) 58% of the groundwater resource. This is the highest value for % constrained potential recharge on Table C.7.3. The only reservation on this statement is that it assumes the area with both salinity and gas constraints can be irrigated by shallow force mode tubewells, which are untested in the area. Akhaura, Bancharampur and Daudkandi thanas could be brought under full irrigation with the installation of STWs only. Homna is in a similar position but would require some deep setting. However, at certain locations in these four thanas, force mode wells might be required to overcome gas problems, or might even be preferred economically, and therefore should not be excluded. In the other thanas force mode wells will be required if 90% of the cultivable area is to be brought under irrigation[3]. The results of this analysis are also shown graphically in Figures C.7.1 and C.7.2.

Table C.7.6 gives a brief description of the groundwater resource potential of each thana of each project zone, however, the comments apply **only** to the results of the potential recharge and depth - storage analysis. In some cases, the conclusions are final, but in others they are partial and require modification or qualification by the detailed modelling using the SCTM and SUTRA models to take account of the effects of salinity and layered aquifer conditions. Indeed, these preliminary results determine where special modelling is needed. For instance, there is no need to consider different abstractions by DTWs from the lower aquifer where the available land can be fully developed by suction mode wells in the upper aquifer.

### C.7.3 Special Groundwater Modelling Techniques

The results and analysis described in sections C.7.1 and C.7.2 require qualification to take account of the influence of multi-layered aquifer conditions, and the possible effect of upconing of saline water from the deep to the shallow aquifer. The modelling approach used the Single Cell Thana Model (SCTM) to look at the effect of layering on water levels, and a numerical model of solute transport (SUTRA).

#### C.7.3.1 Modelling Multi-Layered Aquifer Conditions

Although multi-layered aquifer conditions are present in three areas - Daudkandi, Muradnagar-Debidwar, and Kasba-Nabinagar (Figure 3.2). However, it is not necessary to evaluate the impacts on water levels in Daudkandi or Kasba-Nabinagar because the preceding analysis has shown that the these areas may be fully developed by suction mode wells which would be preferentially constructed in the shallow aquifer, hence only two thanas have been evaluated.

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3 Economically and socially it might be better to irrigate less than 90% of the land if the increment of land is small, and it would require replacing less many shallow tubewells to bring this land under irrigation.

TABLE C.7.6

Appraisal of Potential Recharge and Depth - Storage Modelling Results

| Zone | Thana | Observations | Further Analysis Required |
|---|---|---|---|
| A | Comilla and Burichang | Hydrogeologically these (partial) thanas may be considered as one unit. Already has high irrigation coverage (66%). Calculated potentials show the development is between the STW and DSSTW limits, which is totally consistent with observed water levels and deep setting in 1991. No further potential for STWs, but small increase in DSSTW coverage possible (up to 71% of cultivable area). Further expansion will require additional force mode wells (which are already well established) and deep setting of some existing STWs. Abandonment of a few DSSTWs possible, but unlikely (unless for economic reasons). | None<br><br>(It is noted, however, that there is no water level monitoring well in this part of the thana.) |
| | Brahmanpara | Quite good existing, mixed mode, irrigation coverage (56%). Almost saturated with surface set STWs, as shown by constrained potential equal to abstraction (1991), and deep setting noted in 1989 but not 1991. Good potential for expansion of DSSTWs (up to 81% of area) and any further demand may be met by moderate expansion of force mode wells. No abandonment of DSSTWs anticipated, even at full development. | None |
| | Debidwar | Very low existing irrigation coverage (28%) based on mixed STW and LLP) mainly due to gas constraints on suction mode wells and a historically restricted 'supply' of DTWs. Useful expansion of DSSTWs (up to 48% of area) possible, but only in some areas. Expansion of irrigation in gas prone areas requires large increase in force mode tubewells, however, this natural zoning will moderate drawdown effects on suction mode wells. | Use SCTM to investigate the effect of double aquifer condition on water levels. |

| | | | |
|---|---|---|---|
| B | Kasha | Moderately good existing, mixed mode, irrigation coverage (52%), but mainly from LLPs. There are no major constraints. Some expansion of surface set STWs possible (up to 65% of area), and increase of deep setting could provide all future irrigation requirements (up to 82% of area). Force mode wells probably not required (unless preferred economically). | None |
| | Akhaura | Almost fully irrigated (80%), any further requirement can be met by expansion of surface set STWs. | None |
| | Nabinagar (minor part) | Only two unions included, but apparently subject to gas constraints, and may require irrigation development by force mode wells. | |
| C | Muradnagar | Very low existing irrigation coverage (28%) and most constrained groundwater development opportunities, with both gas and salinity problems. The 'supply' of DTWs was restricted until 1987. Current abstraction already equal to the STW limit. Expansion of DSSTWs possible (up to 34% of area), but only in very restricted areas. However, normal DTWs or low capacity FMTWs can be developed in most of the thana, and low capacity FMTWs (and manual tubewells) can be developed in the shallow aquifer in the area affected by salinity and gas. | Use SUTRA to investigate long term migration of saline groundwater from the deep aquifer to wells pumping from the shallow aquifer.<br><br>Use SCTM to assess differential drawdowns in deep and shallow aquifers. |
| | Nabinagar (major part) | Moderate existing irrigation coverage (37%) dominated by surface water sources. STWs heavily constrained by gas problems, and 'supply' of DTWs restricted until 1987, but still has significant scope for expansion of both STWs (up to 60% of area) an DSSTWs (up to 73%), **but not in all areas**. Promotion and expansion of force mode tubewells will be required in areas of gas constraints. Water levels, however, are of relatively little concern here. | None |

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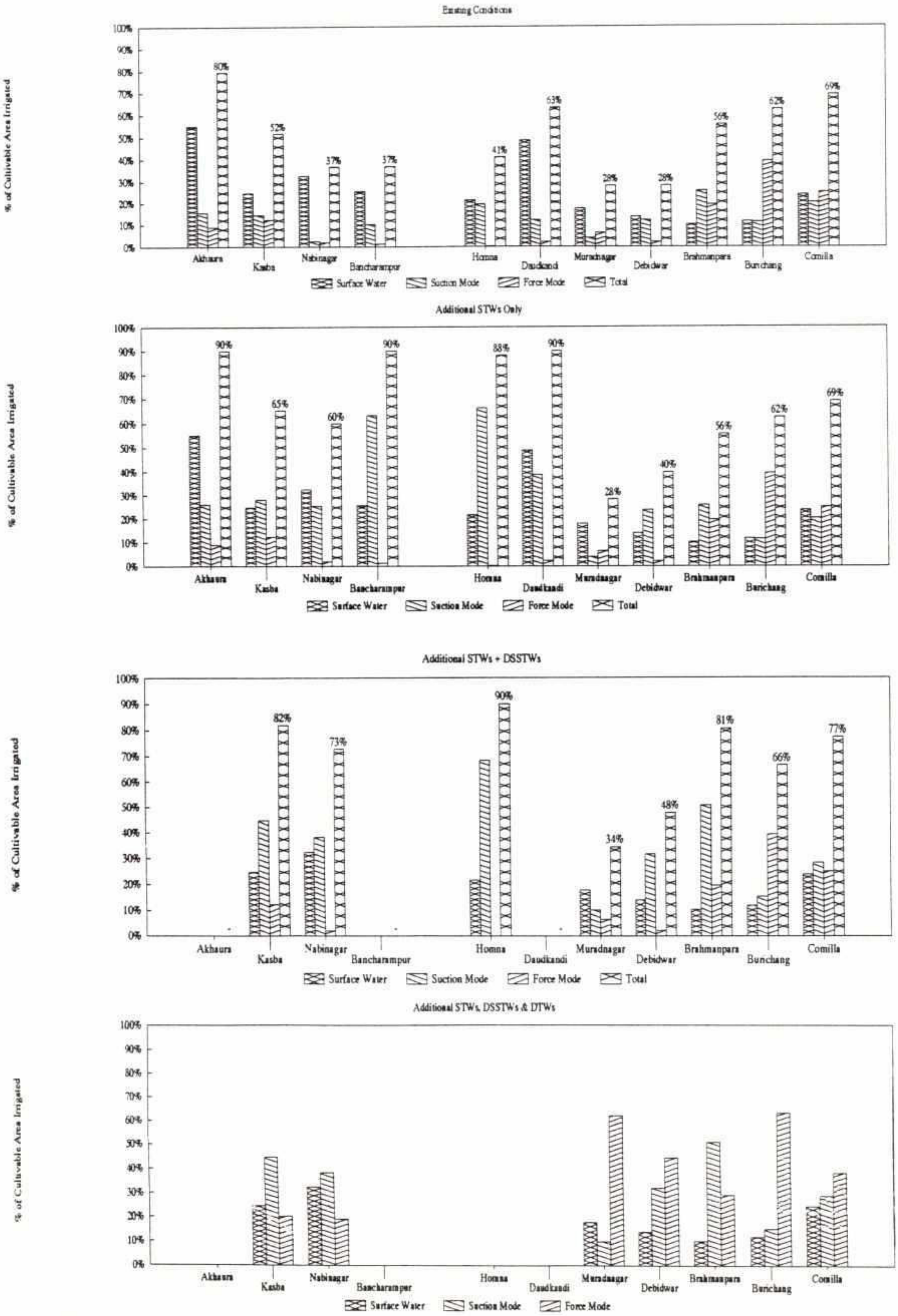
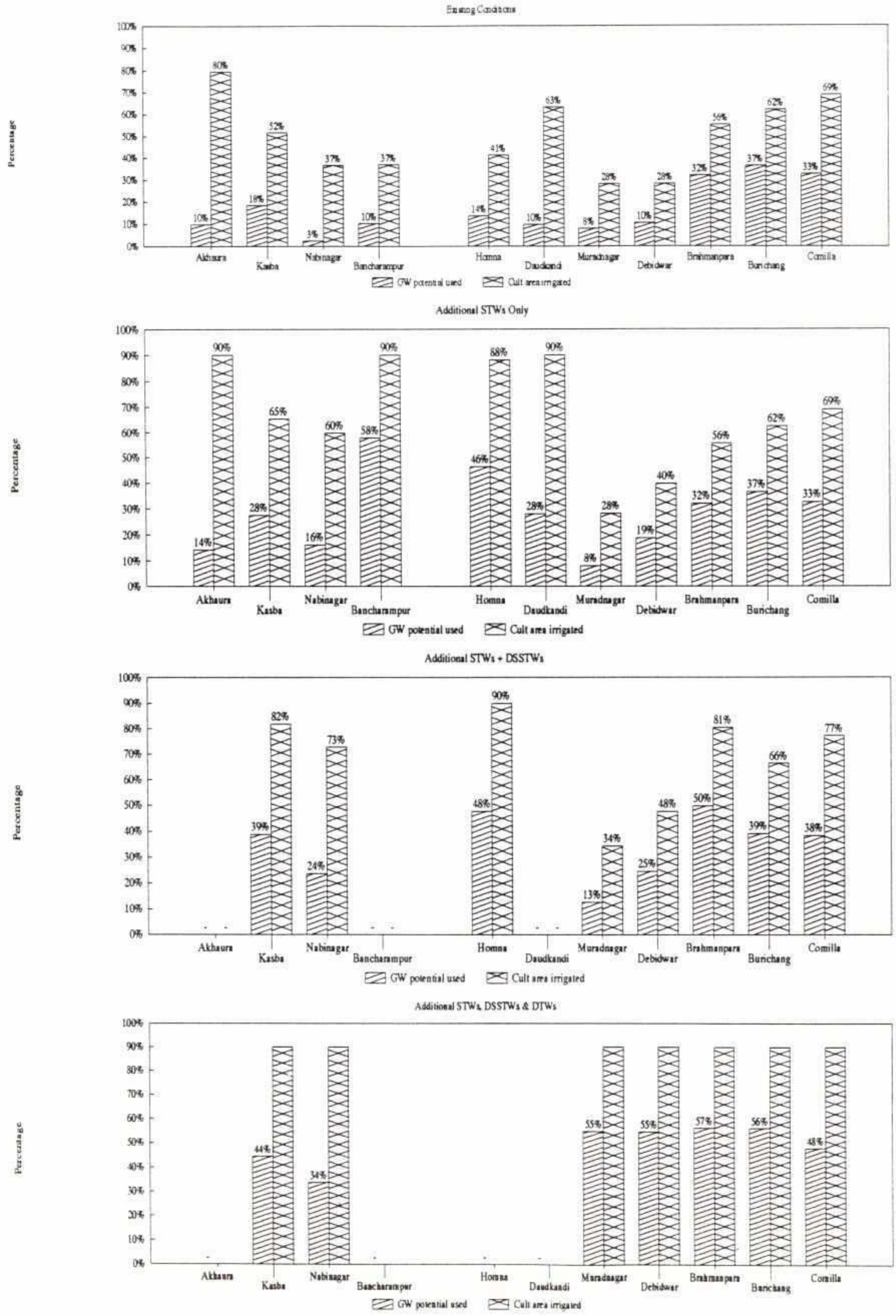
| | | | |
|---|---|---|---|
| D | Daudkandi | Existing irrigation coverage is high (63%), dominated by surface water, and some STWs. There are localised gas constraints on STW development, and a minor salinity constraint on DTW development. The latter is no significance, because that area may be fully developed by suction mode wells in the shallow aquifer. On average the residual area could be irrigated by STWs alone, but in practice FMTWs will be required at some sites because of gas problems. Water level drawdown due to pumping will not be of concern, and will be difficult to distinguish within the natural hydrograph. | None |
| | Homna | Existing irrigation coverage is moderate (41%), with surface water and STWs of roughly equal importance. No DTWs were installed until 1991. There is a small salinity and gas constraints in the east (as Muradnagar) where shallow, low capacity force mode tubewells will be required. Elsewhere demand for irrigation can be met by expansion of STWs. Deep setting will be negligible, except perhaps in drought years. | Evaluate salinity effects using SUTRA (as Muradnagar). |
| | Bancharampur | Similar to Homna. Moderate existing irrigation coverage (37%), but surface water sources are more important. Small gas and salinity constraints in the south east, where shallow, low capacity force mode tubewells may be required. Elsewhere demand for irrigation can be fully met by expansion of STWs. Again no significant deep setting is expected. | As Homna. |
| | Nabinagar (minor part) | Groundwater development in these three unions in the west of Nabinagar are seriously constrained by gas problems and will require FMTWs. | None |

## Figure C.7.1
# Incremental Irrigation to 90% of Cultivable Area




Note : 90% of cultivable area may be irrigated in all thanas if force mode tubewells are used.

## Figure C.7.2
## Resource Usage with Groundwater Irrigation



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The Single Cell Thana Model (SCTM) was originally developed for the South East Regional Study (FAP:5). Its formulation is similar to the model developed for the Special Study Areas of the National Water Plan (MPO, 1990). Basic documentation for the model is given in Appendix C.VI. The model functions as a single cell, finite difference model simulating the groundwater hydrograph for actual rainfall records for the period 1972 to 1989, and a synthesised flood hydrograph. The model was used with each cell equivalent to a thana. The model has the flexibility to be used with either two layer or four layer geometries. Only the latter is considered here:

| | | Model Name | Typical Lithology |
|---|---|---|---|
| SCTM four layer model: | - | upper aquitard | clayey silt |
| | - | upper aquifer | fine to medium sand |
| | - | lower aquitard | sandy silt |
| | - | lower aquifer | medium to coarse sand |

Different permeabilities may be assigned to each layer, vertical permeabilities to the aquitards to control recharge and leakage between the aquifers; and horizontal permeabilities to the aquifers (even though there is no horizontal flow) to calculate drawdowns in pumping wells. There is a particular uncertainty in specifying the permeability of the upper aquifer because no pumping tests have been carried on it. On the basis of grain size, it might be expected that the upper aquifer would be less permeable, however, it is thought that the upper aquifer is part of the Chandina Formation and the lower part of Dupi Tila Formation. By comparison with Greater Dhaka it thought that the younger, unweathered Chandina Formation (and approximate time equivalent of the Dhamrai Formation) may be at least as permeable as the Dupi Tila, where the intrinsic permeability has been reduced by the formation of secondary clay and iron minerals. There are also no determinations of the permeability of the lower aquitard.

Specification of the model parameters has made full use of the latest data available from the DTW II Project and the 1991 AST-CIDA irrigation census. The DTW records were processed using a modification of the DTW II database programs. The model aquifer geometries and permeabilities adopted for each thana were derived from the average profiles in Appendix C.IV and are shown in Table C.7.7. The base of the lower aquifer was taken as the average depth of deep tubewells.

In the model, it is assumed that STWs, DSSTWs and manual tubewells draw water from the upper aquifer, and the proportion of abstraction from the upper and lower aquifers must be specified. Initially the proportion from the lower aquifer was taken as the force mode tubewell abstraction required for full development in Table C.7.3. The objective is to abstract as much additional groundwater as possible from suction mode wells in the upper aquifer.

The current areas irrigated by each technology were taken from the AST/CIDA inventory of minor irrigation for March 1991. Groundwater abstraction may be specified to be from either the upper or lower aquifers. A specified proportion of cultivable land is irrigated from surface water; in the model existing surface water irrigation is held constant with time. This does not imply a prediction of future irrigation patterns except in that it is not expected to decrease. For most of the area, static surface water irrigation approximates a probable worst case for groundwater development, in that any increase in surface water irrigation would also increase the availability of the groundwater resource through increased deep percolation.

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TABLE C.7.7

Aquifer Configuration for the SCTM Model

| | Muradnagar | Debidwar |
|---|---|---|
| **Average Elevations (m)** | | |
| Ground Surface | 4.0 | 4.8 |
| Upper Aquitard | -3 | -18 |
| Upper Aquifer | -33 | -29 |
| Lower Aquitard | -43 | -44 |
| Lower Aquifer | -95 | -104 |
| **Permeabilities (m/d)** | | |
| Upper Aquitard | 0.1 | 0.1 |
| Upper Aquifer | 20 | 20 |
| Lower Aquitard | 0.01 | 0.01 |
| Lower Aquifer | 23 | 22 |

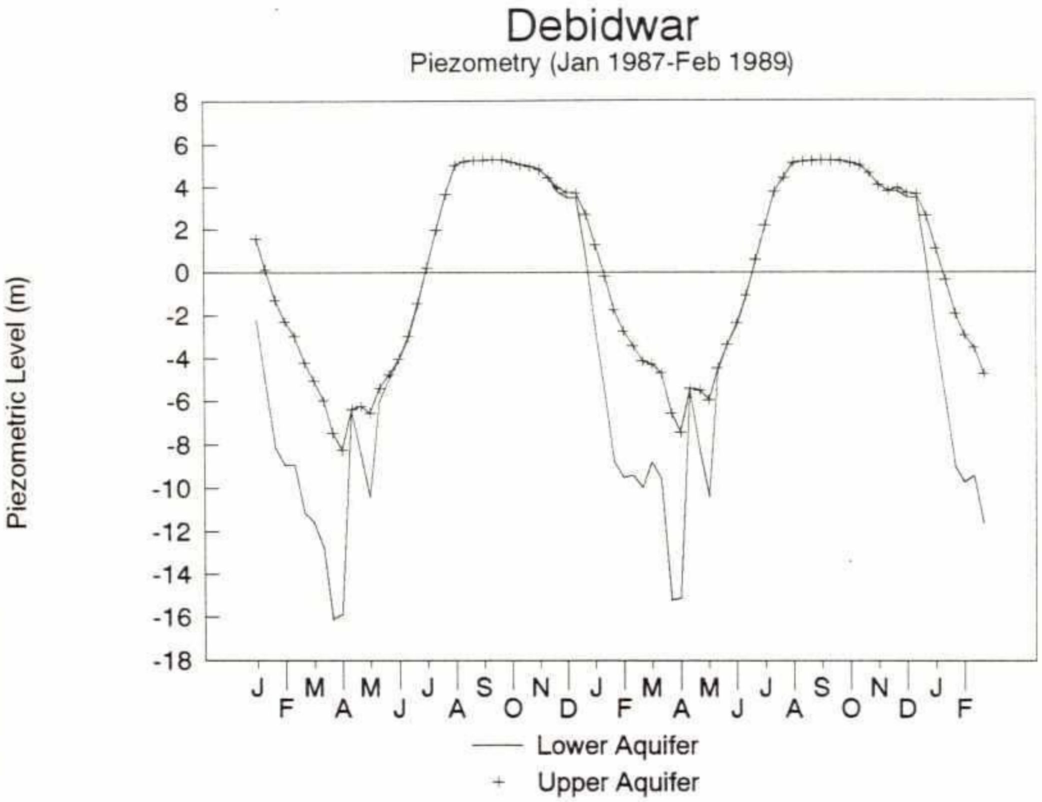
Non-agricultural abstraction of groundwater is predominantly for domestic use. A planning allocation of 100 l/head/day was made (much greater than actual abstraction) in line with the FAP:5 regional plan. The volume of water withdrawn was based on the 1981 census data inflated to 1992 at 2.2% a year.

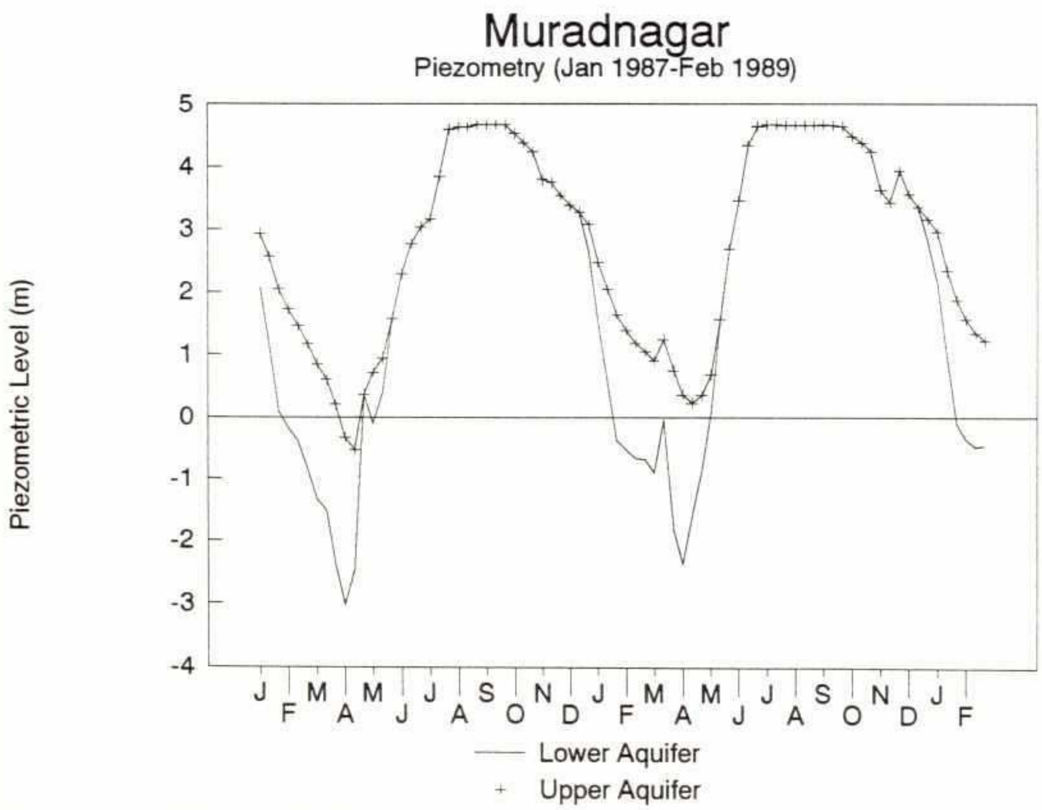
**Results**

The SCTM Model presents its results by predicting what would have been the impact of full groundwater development on the historical meteorological data for the period 1972 to 1989. The main output is in the form of groundwater hydrographs as shown in Figure C.7.3. It must be emphasised that these figures describe the whole of the thana within the project, and in reality there will be significant variations, and in particular do not give full weight to force mode tubewells development in the main aquifer, which if significant would reduce the head differences. In both cases, for the most probable representative set of hydrogeological parameters, it is anticipated the significant head differences will develop between the upper and lower aquifers. For Muradnagar, where the upper aquifer is thicker, the head differences may be of the order of 3-4 metres, with static levels in the lower aquifer falling to around 7 m below ground, while levels in the upper aquifer should lie comfortably within suction limits (although gas constrains this mode of development). Larger head differences are expected in Debidwar, because the thicker upper aquitard and thinner lower aquifer, head differences of 6 - 8 metres are considered probable. Levels in both the upper and lower aquifers are expected to be deeper than in Muradnagar, and water levels in the shallow aquifer may constrain suction mode wells (in the gas free areas).

The SCTM Model has identified the critical importance of the vertical permeability of the lower aquitard, especially in Debidwar. There are field determinations of permeability of this layer in the Gumti Phase II area, and there are also uncertainties about the lateral continuity of the lower aquitard, which would also affect the rate of leakage between the aquifers. Figure C.7.4 shows the critical sensitivity of the model results for Debidwar to the vertical permeability of the lower aquitard. The most probable permeability is thought to be

**Figure C.7.3**
**SCTM Model Hydrographs for Full Groundwater Development**




Notes: 1. SCTM - Single Cell Thana Model of the order of 0.01 m/d. However, if the range of parameter uncertainty is considered to be plus or minus one order of magnitude, then it is seen that the possible aquifer responses is between no significant head difference on the one hand and many tens of metres on the other. Actually the lowest permeability case in Figure C.7.4 is not a credible development scenario because before such water levels are attained, expansion of irrigation would stop because well construction is too difficult or the pumping cost becomes uneconomic. To properly evaluate the potential of the lower aquifer in Debidwar, it is necessary to have a better definition of the permeability of the lower aquitard. This may be done by direct measurement or (better) by careful monitoring of water levels and abstraction in both aquifers through a complete recharge - discharge cycle (e.g December to July).

### C.7.3.2 Upconing of Saline Groundwater

**Conceptual Model**

Salinity has been identified as a constraint to groundwater development from the main aquifer in the western part of Muradnagar and small parts of adjoining thanas. The hypothesis to be tested here is whether it is possible to abstract groundwater for irrigation through shallow force mode tubewells in the upper aquifer without contaminating the upper aquifer by saline upconing from the lower aquifer. Conceptually, the possibility of saline upconing has been considered in relation to the geological conditions in the west of Muradnagar as revealed by the two boreholes shown in Figure 4.3. This has been simplified as:

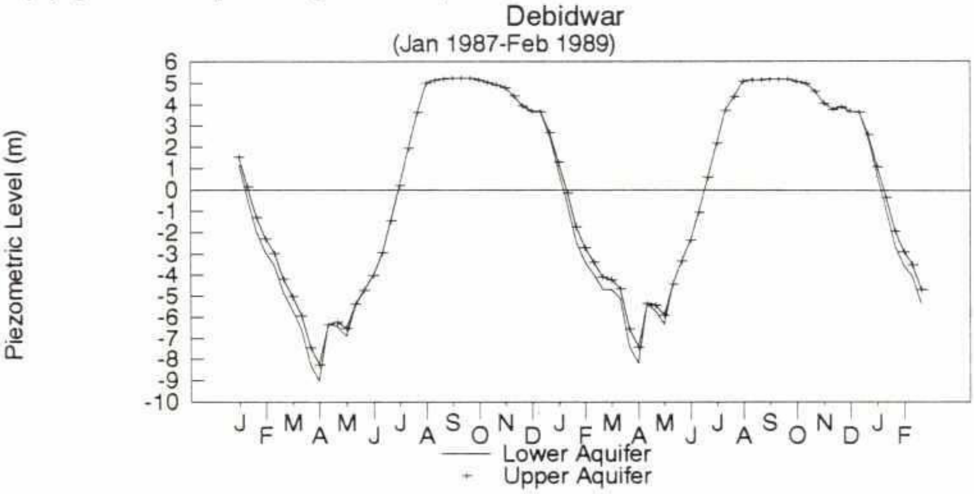
- layer 1 - 3 metres of clayey silt
- layer 2 - 30 metres of grey unweathered, fine to medium sands, with a horizontal permeability of 20 m/d, and containing fresh water with an average salinity of 250 mg/l. This is the potential aquifer for exploitation by shallow force mode tubewells.
- layer 3 - 30 metres of grey fine sandy silt, the vertical permeability is not known and therefore a value of 0.5 m/d has been assumed. This value is very probably too high, however, assuming a high value leads to a safer model prediction.
- layer 4 - 25 metres of grey, weathered medium to coarse sand with a permeability of 23 m/d and containing brackish water with a salinity of 4,000 mg/l. This is the main aquifer exploited by DTWs when not saline.

The analysis assumes that wells would have a nominal half cusec (14 l/s) capacity and be constructed with 12 metres of well screen. To minimise any risk of upconing the well screen would be set as high in the aquifer as possible without running into dewatering problems at the end of the dry season. The problem does not require stability under steady state conditions because the pumping period each year would not exceed 100 days and would be followed by a 265 day recovery period. The possibility of upconing has been analysed using both analytical and numerical models. The models employed do not directly allow the inclusion of layering, but require that these effects are incorporated as anisotropic permeability. Hence in the models, horizontal permeability is defined as the arithmetic mean ($K_h$ 25 m/d) of the layer permeabilities above the saline interface, and the vertical permeability as the geometric mean ($K_v$ 0.25 m/d). And since vertical permeability is critical in determining the rate of upconing, the analysis was also carried out with the vertical permeability increased by a factor of ten. A porosity of 25% was used throughout.

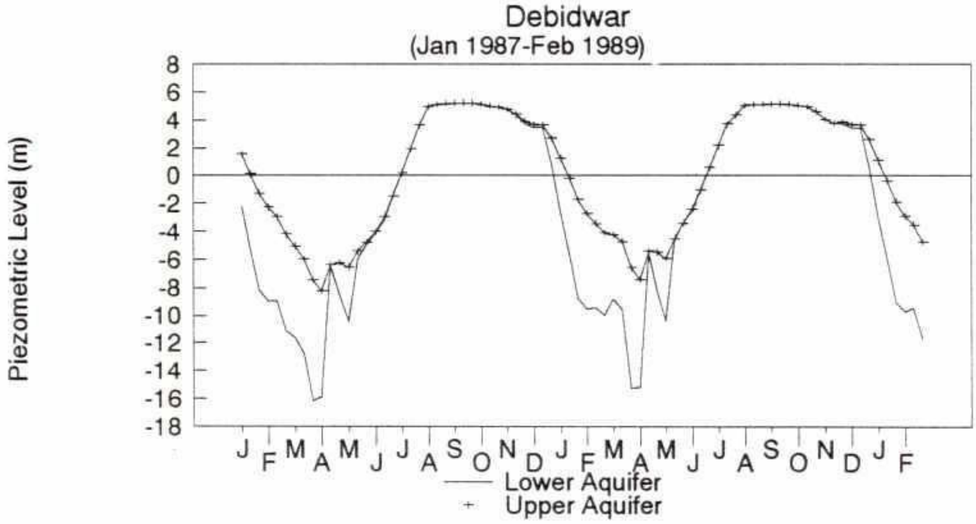
**Figure C.7.4**

## Sensitivity to the Vertical Permeability of the Lower Aquitard in Debidwar

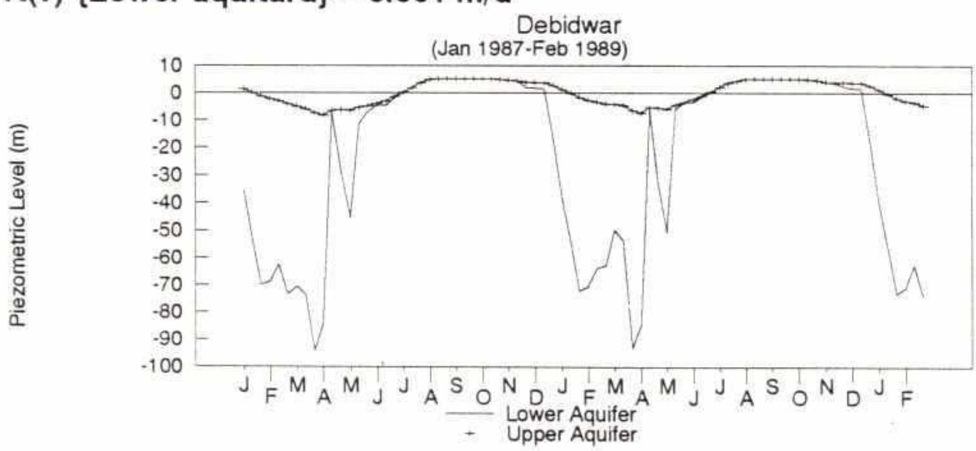
### K(v) {Lower aquitard} = 0.1 m/d




### K(v) {Lower aquitard} = 0.01 m/d




### K(v) {Lower aquitard} = 0.001 m/d




Notes: The graphs show the influence of the probable range of vertical permeability of the lower aquitard in Debidwar, and highlight how the range of uncertainty is critical to predicting whether or not the land resources can be fully developed by groundwater for irrigation.

**Analytical model of Schmorak and Mercado (1969)**

This model analyses with the rise of a sharp interface beneath a partially penetrating pumping well. The initial interface is assumed to be horizontal, and that hydrodynamic dispersion is negligible. The aquifer is of infinite horizontal extent and receives no recharge (which is not unreasonable for the dry season). Schmorak and Mercado presented equations for the calculating the position of the interface at any time after the start of pumping, and for the critical interface rise and associated discharge at which salt water enters the well with a sudden jump. Vertical permeability is the most uncertain parameter, but affects only the rate of upconing and not the absolute rise of the interface. The design factors that control upconing are the discharge and the distance between the base of the well and the initial interface position. It is strongly recommended that only low discharge tubewells (say 14 l/s) are promoted in the saline areas. The results of the model (Table C.7.8) are most usefully expressed in terms of the critical upconing distance and the time taken for the critical upconing to be attained. The results in Table C.7.8 suggest that provided the depth of the well is kept within 30 metres of ground level there should be a negligible risk of upconing, and as was suggested earlier, the vertical permeabilities quoted in the table are probably too high, but if so this merely reinforces the conclusion. Appendix C.V gives further details of the model and its results.

**TABLE C.7.8**

**Predictions of Saline Interface Upconing for 14 l/s FMTWs**

| Depth to Base of Well m | Distance above Interface m | Critical Upconing Distance m | Time for Critical Upconing (years) *where* $K_v$ = 0.25 m/d | *and* $K_v$ = 2.5 m/d |
|---|---|---|---|---|
| 18 | 47 | 11.8 | 14.4 | 2.9 |
| 24 | 41 | 10.3 | 8.5 | 1.7 |
| 30 | 35 | 8.8 | 4.8 | 0.95 |
| 36 | 29 | 7.3 | 2.5 | 0.50 |
| 42 | 23 | 5.8 | 1.2 | 0.25 |

**Numerical Solute Transport Model**

The analytical model described above does not consider the effects of dispersion, which were considering the same problem with a numerical model. The Saturated - Unsaturated Transport Model (SUTRA) is a groundwater flow and solute transport is used to evaluate the potential for migration of saline groundwater. The model was developed by the USGS and uses both the finite element and integrated finite difference techniques. The model is highly versatile and is described in full in USGS Water Resources Investigation Report 84-4369.

The SUTRA model was configured as a rectangular grid in the vertical plane with 18 columns, extending radially to 174 metres and 21 rows down to 83 metres. The production well discharges at 1200 $m^3$/d and has a well screen from 12 to 24 metres below ground. The initial interface was placed at 59 metres, with a static water level at 2.5 metres. There is no precedent for defining longitudinal and transverse dispersion coefficients for such aquifers in Bangladesh, but by comparison with international data, values of 5 and 0.1 metres were considered reasonable. The model was run for a period of 200 days, double the length of the irrigation season. details of the model output are given in Appendix C.V. The SUTRA simulation indicates that after 100 days water with a salinity of 2000 mg/l would rise to 55 m (below ground) and water with a salinity of 440 mg/l would rise to 47 m. Even after 200 days of continuous pumping, the water at 55 m would attain a salinity of 2,500 mg/l, and water at 47 metres would rise to a salinity of 760 mg/l. In other words, after twice the probable maximum pumping period there would more than 20 metres of uncontaminated water beneath the bottom of the well.

#### C.7.3.3 Implications of Modelling for Resource Potentials

The SCTM Model has demonstrated the probability of a head differential developing between the upper and lower aquifers in Muradnagar and Debidwar. In Muradnagar, drawdown in both aquifers may be moderate, but in Debidwar it has been shown that under the present state of knowledge, it is possible that it may not be practical to fully develop groundwater for irrigation. Careful monitoring of water levels and abstraction in both aquifers through one complete irrigation season and the following recovery period is recommended to resolve this issue.

The analytical and numerical models of salt water upconing indicate that, provided well depths are kept as shallow as possible, short term (100 days) annual pumping of groundwater from the shallow aquifer poses very little risk of saline contamination. Hence, provided that shallow force mode tubewells (SFMTWs) can successfully the problems of gas discharges, groundwater may be developed for irrigation even in the saline zones. However, some caution is still recommended, and the wells should be promoted on a pilot basis at first, and then monitored annually for any sign of progressively deteriorating water quality.

### C.7.4 Impact of Possible FCD and FCD/I Interventions

Other things being equal, any reduction in the depth and duration of flooding must reduce the maximum quantity of infiltration that might occur (as in the MPO Recharge Model) into an infinite reservoir beneath the soil zone. However, as was shown in sections C.7.1 and C.7.2, the available groundwater resource exceeds the probable demand for irrigation and potable supply, and hence a reduction of potential groundwater recharge is not necessarily a negative impact on groundwater irrigation. The highest anticipated use of available groundwater to achieve irrigation on 90% of cultivable land is 58% in Bancharampur. Also, as may be seen from the hydrographs in Appendix C.III, the additional recharge that occurs during events such the flood of 1988 is no practical value into groundwater users in the following dry season. Groundwater levels at the start of the irrigation season (the end of January) are evidently controlled by the bed levels of the (natural and man-made) surface water drainage network, and the meteorological and hydrological conditions during the preceding few weeks (rather than months). Years with moderate flood depths have similarly little effect on the following dry season. It is probable that reducing the duration of flooding has a greater effect than reducing its depth.

However, it appears from the hydrographs in Appendix C.III suggest that the aquifer is 'rejecting useful recharge' for at least two months.

The impact of full flood protection on potential recharge and hence usable recharge was investigated under SERS by re-running the MPO Potential Recharge Model with a synthetic flood hydrograph in which flooding is completely removed from all flood phases. In reality, such complete protection could not be achieved, however, the analysis is satisfactory for evaluating the worst possible impact on the groundwater resource. Indeed, it is unlikely that any such intervention would be proposed, except in urban areas, it serves as a convenient worst case analysis for the impact of the FCD option under the BWDB Study. It is seen that in Nabinagar, Homna, Daudkandi and Muradnagar flood prevention would not reduce the groundwater potential at all. Flood prevention in Bancharampur can reasonably be assumed to have a similar effect to these thanas. The greatest reduction of potential recharge would be in Akhaura, however, this thana already has about 80% of its cultivable area under irrigation, and dominantly from surface water. Therefore no adverse effect is anticipated in Akhaura unless the same flood control and drainage measures also seriously reduce the availability of surface water and hence increase the demand for groundwater. For the thanas where a reduction in usable recharge is predicted, Table C.7.9 also shows the abstraction that would be required if current irrigation were developed to its practical limit using groundwater. With the same proviso, that existing surface irrigation is not reduced, it appears that flood control and drainage schemes do not pose a serious threat to groundwater development for irrigation.

**TABLE C.7.9**

**Effect of Full Flood Protection on Usable Recharge**

| Thana | MPO Groundwater Potential NFP mm | FFP mm | Reduction due to Flood Protection | Abstraction Required for Full Development (mm) |
|---|---|---|---|---|
| Akhaura | 738 | 327 | 56% | 120 |
| Kasba | 506 | 405 | 20% | 295 |
| Nabinagar | 288 | 288 | 0% | |
| Bancharampur | *Not assessed under MPO Phase II* | | | |
| Homna | 507 | 507 | 0% | |
| Daudkandi | 364 | 364 | 0% | |
| Muradnagar | 425 | 425 | 0% | |
| Debidwar | 566 | 457 | 19% | 328 |
| Brahmanpara | 599 | 506 | 16% | 293 |
| Burichang | 482 | 458 | 5% | 293 |
| Comilla | 669 | 599 | 10% | 261 |

Source : National Water Plan Phase II, and Southeast Regional Study (1991)
Note : NFP - no flood protection, FFP - full flood protection

As noted in section C.6.5, any project interventions that include a surface water irrigation component will both reduce the demand for groundwater, increase its availability, and reduce the water table lowering due to groundwater pumping in the dry season.

### C.7.5 Impact of Reduced Surface Water Irrigation on Groundwater Resources

It has been shown earlier that the surface water irrigation is complimentary to groundwater development in an area since it provides a source of recharge during the dry season, both increasing the total availability of groundwater and reducing the lowering of the water table (and reducing pumping costs). In the preceding analysis it has been assumed the surface water irrigation would at least be maintained at its present level. However, it is understood that a new irrigation will shortly be commissioned in India that will drastically reduce the dry season flows in the Gumti River. This will mainly affect Comilla, Burichang, Brahmanpara, Debidwar and Muradnagar. The magnitude of this reduction is not known, and will presumably be progressive, but there can be little doubt that this will result in reduced LLP irrigation in Zone A and parts of Zone C.

To give an indication of the possible impact of this on the availability and demand for groundwater irrigation the analysis presented in sections C.7.1 and C.7.2 was repeated for reduced existing surface water irrigation. The reduction was simulated by setting to zero all surface water irrigation in all DAE Blocks (Appendix C.II) that border the Gumti River. This is probably somewhat worse than might actually be experienced, but not a totally unreasonable approximation of the effect. The results are shown in Tables C.7.10 and C.7.11. In those parts of Comilla, Burichang and Debidwar that lie in the Gumti Pase II area the effect on existing surface water irrigation would be dramatic, for detailed inspection of the AST/CIDA data (Appendix C.II) that almost all of the LLP and traditional irrigation lies within a band perhaps 1.0 to 1.5 km wide along the banks of the Gumti River, and in which there is negligible groundwater irrigation. The reverse applies further away from the river.

**TABLE C.7.10**

**Impact of Non-Availability of Gumti River Water on the Surface Water Irrigation**

| Thana | Irrigated Area Lost ha | Reduction in Surface Irrigation |
|---|---|---|
| Muradnagar | 1519 | 40% |
| Debidwar | 583 | 63% |
| Brahmanpara | 200 | 21% |
| Burichang | 727 | 85% |
| Comilla | 643 | 75% |

If this source of irrigation water is lost, then it seems inevitable that farmers will switch to groundwater. As shown in Table C.7.11 there is sufficient groundwater to support the increased demand, however, there will be negative impacts on the existing users. Without the beneficial effects of dry season recharge from LLP irrigation, the groundwater potentials for all technologies would be reduced. The estimated static water levels at full development would increased by about two metres in the southeast of Zone A. In Burichang and Comilla, current abstraction would exceed both the STW and DSSTW potentials, requiring widespread conversion of STWs to DSSTWs, and DSSTWs to force mode wells. New wells will be mainly use force mode technology. Section C.7.3 earlier noted the possibility of excessively deep water levels developing in Debidwar, this effect would be intensified by loss of LLP irrigation from the Gumti.

## TABLE C.7.11

### Comparison of Resource Estimates with and without Reduced Flows in the Gumti River

| Thana | Net Groundwater Abstraction mm/yr | MPO Phase II Estimates | | DTW(1) Potential mm/yr | SERS Potentials | | With Existing Gumti Flow Constrained Potentials (inc. SW irrigation) | | Without Existing Gumti Flow Constrained Potentials (inc. SW irrigation) | | Reduction | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | STW Potential mm/yr | DSSTW Potential mm/yr | | DSSTW Potential mm/yr | DTW(1) Potential mm/yr | STW Potential mm/yr | DSSTW Potential mm/yr | STW Potential mm/yr | DSSTW Potential mm/yr | STW % | DSSTW % |
| Muradnagar | 44 | 65 | 109 | 425 | 142 | 708 | * 43 | 69 | * 40 | 65 | 7% | 6% |
| Debidwar | 62 | 84 | 147 | 566 | 113 | 566 | 111 | 146 | 88 | 123 | 21% | 16% |
| Brahmanpara | 166 | * 132 | 248 | 597 | * 116 | 496 | * 165 | 258 | * 161 | 254 | 2% | 2% |
| Burichang | 190 | * 73 * | 134 | 482 | * 134 | 495 | * 122 | 204 | * 101 * | 183 | 17% | 10% |
| Comilla | 179 | * 86 * | 164 | 486 | * 157 | 493 | * 170 | 210 | * 130 * | 170 | 24% | 19% |

Notes :

1. * indicates current abstraction greater than estimated potential
2. The constrained potentials for the present study include the additional (dry season) recharge derived from surface water irrigation
3. 'nd' indicates 'not determined'
4. Quantities of water are expressed as a depth of water averaged over the gross area of the thana (inside the the project)
5. SERS - South East Regional Study (FAP:5)

### C.7.6 Impact of Groundwater Irrigation on Drinking Water Supplies

It follows from the water level maps in Chapter C.3 that hand tubewells in Burichang and Comilla already experience problems during the late dry season because of the depth to water, and force mode hand tubewells are required to provide a reliable supply. In other thanas, such problems are likely to be restricted to pockets of very high land. As implied in the previous section (Table C.7.11) these problems would be exacerbated by any reduction reduced flows in the Gumti river.

The impact of further groundwater development on drinking water supplies may be considered in terms of the three phases set out earlier in Table C.7.3. Full development of the STW potential being itself limited by suction cannot cause a major deterioration of dry season water supplies, such effects will be restricted to pockets of higher land. With full development of the DSSTW potential, Brahmanpara and Kasba would also require the installation of force mode hand tubewells. If the groundwater resource is developed to its maximum potential using force mode tubewells (only after the suction mode potential is exhausted) there would actually relatively little impact on drinking water supplies. The greatest impact on irrigated area (Table C.7.3) would be in Burichang, Debidwar and Muradnagar. Water levels in Burichang already exceed suction limits in the dry season, although more wells will be affected, while in Debidwar and Muradnagar ti is likely that the hand tubewells will continue to operate effectively from the shallow aquifer, despite deeper water levels in the main aquifer.

An indirect consequence of increased groundwater irrigation would probably be the increased use of fertilisers and pesticides which could affect the quality of drinking water. The same concerns would apply to increased surface water irrigation, although with groundwater pumping the possibility of contaminants infiltrating further or faster are greater. As a general precaution, installation of wells with deeper screens and improved sanitary seals is recommended.

## C.8 Economics of Groundwater Development

### C.8.1 Costs of Groundwater Development

This study has been prepared during a period of profound change in the tubewell irrigation sub-sector. During the late 1980's shallow tubewell construction was successfully transferred to the private sector; a situation that is not expected to change. Deep tubewell irrigation is about to undergo profound change, as the forthcoming NMIDP project intends to assist privatisation of the DTW sub-sector. Traditionally DTW designs in Bangladesh have been dictated by the objectives of high capacity designs aimed at achieving an optimum based on a (subsidised) high capital cost, low operating cost. Given the nature of investment opportunities and credit availability in rural areas, designs will switch to sub-optimum, minimum capital cost - high operating cost - short life type. During the 1980's, all BADC's DTWs were sold to co-operatives, and only one discharge capacity was available. In practice, co-operative organisation of the large number (often more than a hundred) of farmers needed to take advantage of the theoretical economies of scale were rarely achieved. In future, groups are likely to be smaller and pump capacities selected to suit the specific requirements of the scheme.

The preceding chapters have drawn attention to the need for a variety of force mode tubewells. There is little basis experience for predicting the capital and operating costs, and command areas for such wells. However, a major preparatory study (the Minor Irrigation Technologies Study) for NMIDP was carried out under the DTW II Project (MMI, 1992, vols. 2.2/4.1-4.3). Until NMIDP gains practical experience, that study probably provides the best estimates of the likely costs of force mode irrigation under private sector operation, and this chapter draws extensively on its conclusions. Those findings are supported by a theoretical analysis of deep and shallow tubewell irrigation[1] in Appendix C.VII.

Table C.8.1 gives a summary of the expected capital and operating costs of suction and force mode tubewells. The designs quoted are arbitrary selections from what should be seen as a continuum of design options, selected to show some typical examples of the possible range. The force mode designs are basically similar to those shown earlier in Figure C.6.2. Many of these designs may be economically sub-optimum, being biased towards low capital cost, however, as most economic studies of tubewell design have shown parameters such as screen length may varied greatly with little shift in the net present value of total costs (and yet a large shift in the relative proportion of capital and operating costs. The final option in Table C.8.1 (SFMTW 3) will probably not be required, unless it is found that the salinity and shallow gas problems cannot be overcome and it is necessary explore and develop aquifers below the saline zone, as is already being done in Noakhali and Lakshmipur districts.

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1 A theoretical comparison of suction and force mode tubewell irrigation was prepared by the Consultant independently of the Gumti Study, but using the Comilla region as a type area, for publication later in 1993; a draft of that paper is reproduced here in Appendix VII.

In Table C.8.1 only diesel power has been considered. Under current energy policies, electrically operated tubewells are cheaper to operate than diesel powered ones, the price of diesel not having fallen since the Gulf War. However, for most farmers electricity is not available, but they tend to convert when it becomes available. In the longer run it may be anticipated that energy will be available at a more equitable cost.

### C.8.2 Comparative Analysis of Suction and Force Mode Development

Suction and force mode tubewells each have their optimum roles in irrigation (see Appendix C.VII). The primary determinant of this is the depth to water. Under more difficult aquifer conditions, where gas constraints apply, or at more advanced stages of irrigation development there will be a natural transition from suction mode to force mode pumping. Figure C.8.1 shows the cost of pumping water as a function of water level for typical conditions in the Gumti area. The data on this graph may be transposed directly to the information given in Table C.8.1 to analyse irrigation costs under various development scenarios. Figure C.8.2 shows an economic comparison of STW and (private sector) DTW irrigation. Except with very shallow water tables, DTWs are economically preferred when irrigation is examined as an isolated activity. Most of the advantages of STWs lie in their easier financing, smaller group sizes and the possibility of alternative uses for the prime mover. Full details of this analysis are given in Appendix C.VII.

## TABLE C.8.1

### Indicative Capital and Operating Costs of Possible Tubewell Technologies

| Mode | STW | DSSTW | SFMTW(1) | SFMTW(2) | SFMTW(3) | DFMTW(1) | DFMTW(2) | DFMTW(3) |
|---|---|---|---|---|---|---|---|---|
| Discharge (l/s) | 7 | 10 | 15 | 15 | 23 | 30 | 60 | 30 |
| Expected Command Area (ha) | 3.8 | 5.4 | 7.4 | 7.4 | 11.1 | 13.4 | 23.8 | 13.4 |
| Pump chamber length (m) | 0 | 0 | 18 | 12 | 18 | 21 | 24 | 27 |
| Screen length (m) | 12 | 12 | 12 | 12 | 18 | 18 | 24 | 18 |
| Expected well depth (m) | 30 | 30 | 30 | 24 | 36 | 60 | 70 | 150 |
| Blank casing (m) | 18 | 18 | 0 | 0 | 0 | 21 | 22 | 105 |
| Cost of pump chamber (Tk/m) | 0 | 0 | 330 | 330 | 340 | 1250 | 1608 | 1250 |
| Well screen diameter (mm) | 100 | 100 | 100 | 200 | 150 | 150 | 150 | 150 |
| Cost of well screen (Tk/m) | 240 | 240 | 240 | 1280 | 656 | 656 | 656 | 656 |
| Cost of blank casing (Tk/m) | 230 | 230 | 330 | 330 | 340 | 623 | 623 | 623 |
| Unit cost of installation (Tk/m) | 100 | 100 | 300 | 300 | 400 | 500 | 780 | 900 |
| Other costs | 1,700 | 1,700 | 10,000 | 10,000 | 12,000 | 15,000 | 25,000 | 15,000 |
| Total cost of installation | 3,600 | 5,600 | 10,800 | 9,000 | 16,800 | 33,000 | 59,280 | 140,400 |
| Cost of well components | 8,720 | 8,720 | 18,820 | 29,320 | 29,928 | 66,141 | 93,042 | 125,973 |
| Cost of engine and pump | 26,500 | 26,500 | 51,500 | 51,500 | 63,000 | 74,500 | 200,000 | 74,500 |
| Total Capital Cost (Tk) | 38,820 | 40,820 | 81,120 | 89,820 | 109,728 | 173,641 | 352,322 | 340,873 |
| **Capital Cost per hectare (Tk)** | **10,216** | **7,559** | **10,925** | **12,097** | **9,852** | **12,992** | **14,803** | **25,505** |
| Fuel and Lubricants (Tk/ha/yr) | 2,550 | 2,402 | 2,300 | 2,300 | 2,300 | 2,300 | 2,300 | 2,300 |
| Operator & managers salaries etc. | 3,011 | 4,279 | 5,884 | 5,884 | 8,826 | 10,591 | 18,860 | 10,591 |
| **Operating Cost per hectare (Tk)** | **3,342** | **3,194** | **3,092** | **3,092** | **3,092** | **3,092** | **3,092** | **3,092** |

**General Conditions:**

1. Aquifer permeability 20 m/d
2. Average static water level 4 metres
3 Irrigation requirement 800 mm
4. Assumes diesel power, at Tk 14/l
5. All costs assume private sector construction and opertion.

**Notes:**

1. For derivation of costs see Appendix VII, and MMI (1992, v2.2/4)
2. See Figure 6.2 for typical designs
3. SFMTW - shallow force mode tubewell
4. DFMTW - deep force mode tubewell

**Applications**

STW - conventional shallow tubewell
DSSTW - conventional deep set shallow tubewell
SMFTW(1) - For shallow aquifers constrained by gas, or a competitor to the STW.
SMFTW(2) - as above, but with shallow salinity.
SMFTW(3) - Higher capacity version of SFMTW(1)
DFMTW(1) - For deeper aquifer conditions
DFMTW(2) - Private sector version of traditional BADC 2 cusec design
DFMTW(3) - For very deep aquifers



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Figure C.8.1

## Pumping Cost as a Function of Water Table Depth

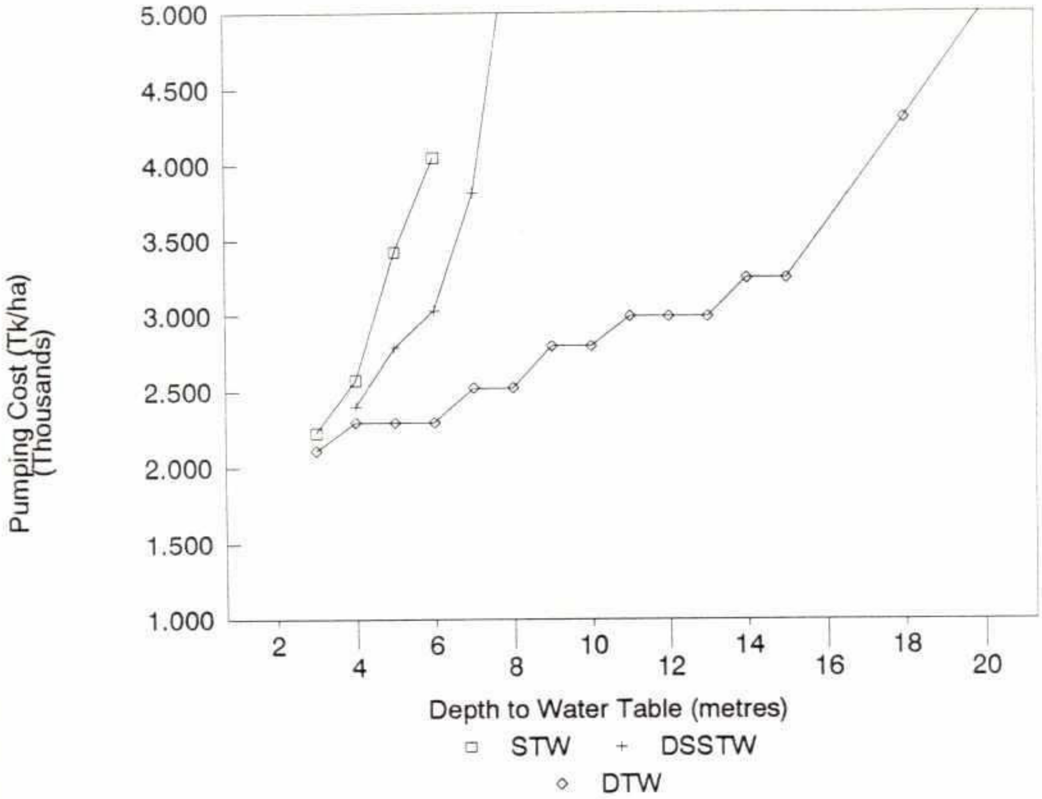
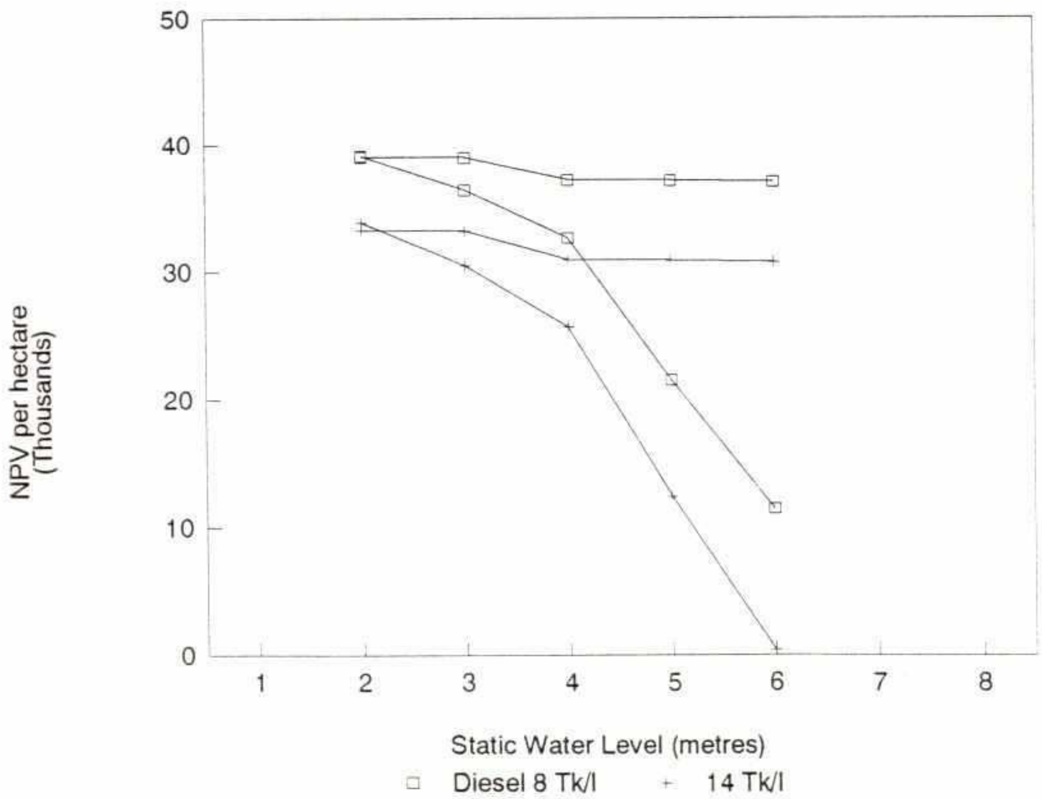



Figure C.8.2

## Economic Comparison of Deep and Shallow Tubewell Irrigation




Note : See Appendix C.VII for deatiled derivation of costs.

## C.9 Conclusions and Recommendations

### C.9.1 Conclusions

The whole of the project area is underlain by productive alluvial aquifers of Quaternary age that are extensively exploited for irrigation and water supply. The aquifers are fully recharged every monsoon through a combination of rainfall and riverine flooding. Minor irrigation devices cover about 65,000 hectares (about 45 % of the cultivable area), of which nearly half is provided by groundwater; this is more than double the irrigation coverage estimated by the BWDB study for their baseline year of 1987. Surface water irrigation has a beneficial effect on groundwater recharge, and significantly increases its availability in the dry season.

There is considerable potential for increased pumping of groundwater on an annually renewable basis in all areas. It is probable that all cultivable land not currently under irrigation could be irrigated from groundwater on an annually renewable basis. In many areas of the study area, specific tubewell technologies are subject to specific constraints. However, groundwater may be developed for drinking water or irrigation by some method in all areas. The principal constraint is discharges of natural gas breaking the suction of STWs and DSSTWs (mainly in Zone C). Gas problems may be overcome by the use of force mode wells. In the western part of Muradnagar the coincidence of gas and salinity will necessitate the development of groundwater by low capacity force mode wells in the shallow, fine grained aquifer. The requirements for full irrigation development are set out in Table C.9.1 and Figure C.9.1.

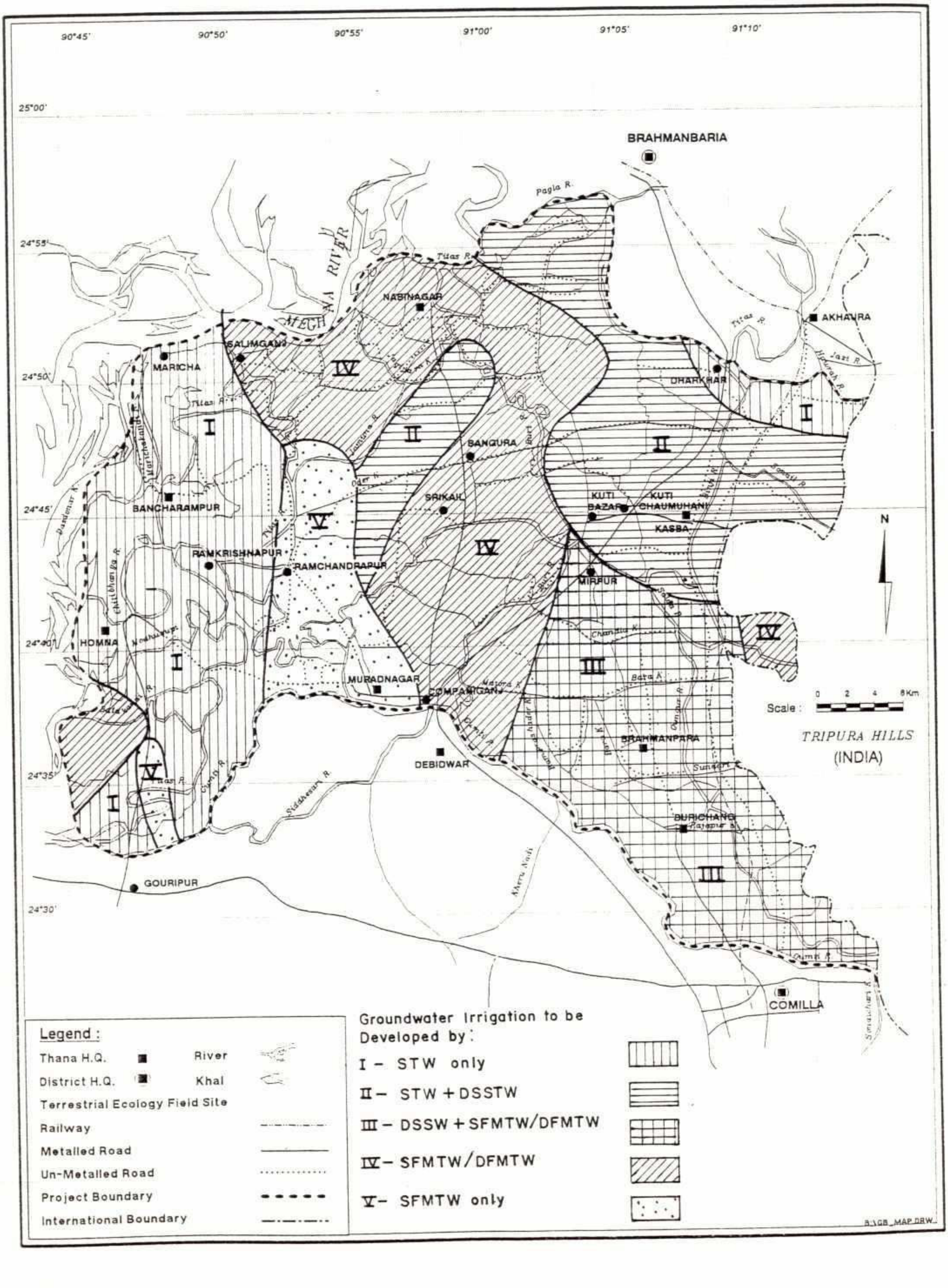
**TABLE C.9.1**

**Technology Requirements for Full Groundwater Irrigation Development**

| Required Tubewell Technology: | | |
|---|---|---|
| **STWs Only** | **DSSTWs** | **FMTWs** |
| Akhaura | Kasba | Nabinagar |
| Bancharampur | Brahmanpara | Muradnagar |
| Homna | | Debidwar |
| Daudkandi | | Burichang |
| | | Comilla |

Groundwater modelling has demonstrated that there is little risk of migration of saline water upwards from the main aquifer in Muradnagar if the shallow aquifer is developed by shallow force mode wells.

## Figure C.9.1
# Groundwater Development Zones



Analysis with the single cell model for Debidwar has shown that, owing to uncertainty about the vertical permeability of the lower aquitard, there is some about whether it would be possible to fully exploit the groundwater resources of the main aquifer without dry season water levels falling below the economic limit.

If constructed, flood control and drainage would reduce the theoretical quantity of recharge to the aquifer every year, however, the residual potential should still be enough to meet all foreseeable demand. If the flow of the Gumti River crossing the Indian Border is reduced it will result in slightly deeper dry season groundwater levels in Zone A, with increased deep setting of shallow tubewells, and increased demand for force mode wells.

Salinity constrains development of the deeper (main) aquifer in some areas, it being unsuitable for either irrigation or drinking. High concentrations of iron and manganese are a pervasive nuisance. Nitrate concentrations sometimes marginally exceed the drinking water standards, and there is concern that this may part of a deteriorating trend.

### C.9.2 Recommendations

A pilot project to demonstrate the viability of using shallow force mode tubewells in the shallow aquifer to overcome gas (and salinity) problems should be undertaken as a matter of some urgency. This problem has never been officially recognised (e.g the National Water Plan) as a constraint on groundwater development, and the area is excluded from the forthcoming National Minor Irrigation Development Project (NMIDP). The definition of the NMIDP project area considered only coastal salinity and potential recharge, and was done without any knowledge of these gas problems.

Groundwater level monitoring network needs to be improved with additional automatic recorders installed in Brahmanpara, and also in Muradnagar and Debidwar where multi-layered aquifer conditions exist and both aquifers should be monitored.

Monitoring and applied research are required into water quality issues, especially the possible migration of saline groundwater, and the possible progressive contamination the shallow aquifer (the regions primary source of safe drinking water) by nitrate. The research should give special importance to quantifying the importance of different sources of nitrate.

# Appendix C.I

## Survey of Natural Gas Discharge Occurrences

## Survey of Natural Gas Discharge Occurrence

Development of both deep and shallow tubewells in the Gumti Phase II area, as recognized but not documented during the BADC DTW II completion phase, is constrained by the occurrence of natural gas discharge. The areas of this problem are not well defined. A ten-day field study was conducted in the project area during the month of October, 1992 to collect information on the nature and extent of natural gas discharges as a constraint on development of tubewells - DTW, STW and HTW. As there has been no written records or formal reports on the problem, the project personnels have held discussions with the BADC officials, BRDB staff, as well as DTW, STW and HTW contractors, in most of the thanas to identify nature and location of problem wells and areas.

Gas discharges have been noted from DTWs, STWs and hand tubewells for drinking water. Gas is observed coming out of solution during the operation of wells. Many times the gas may be ignited, indicating the present of methane. Chemical analyses indicate that significant concentrations of dissolved carbon dioxide are present in the water, and traces of hydrogen sulphide are also noted from their smell. The redox conditions and the abundance of organic matter probably account for the production of gases in the shallow groundwater environment, although leakage from deep strata in the neighbouring Bakhrabad gas field is an alternative source for the gas. Drilling contractors report striking larger pockets of gas during drilling, which sometimes lead to abandonment of the hole, and are potential danger to workers. Drillers and concerned BADC officials report that gas problems occur predominantly in the shallow aquifer.

The locations of deep tubeweels with reported gas problems and the documentary evidences are shown in Figure C.I.1 and Table C.I.1. Problem wells are largely restricted to Muradnagar and Daudkandi Thanas. In the majority of cases gas is a nuisunce for DTWs, and may reduce the working life of pumpsets by promoting corrosion but only a very small proportion of problem wells cannot be operated usefully.

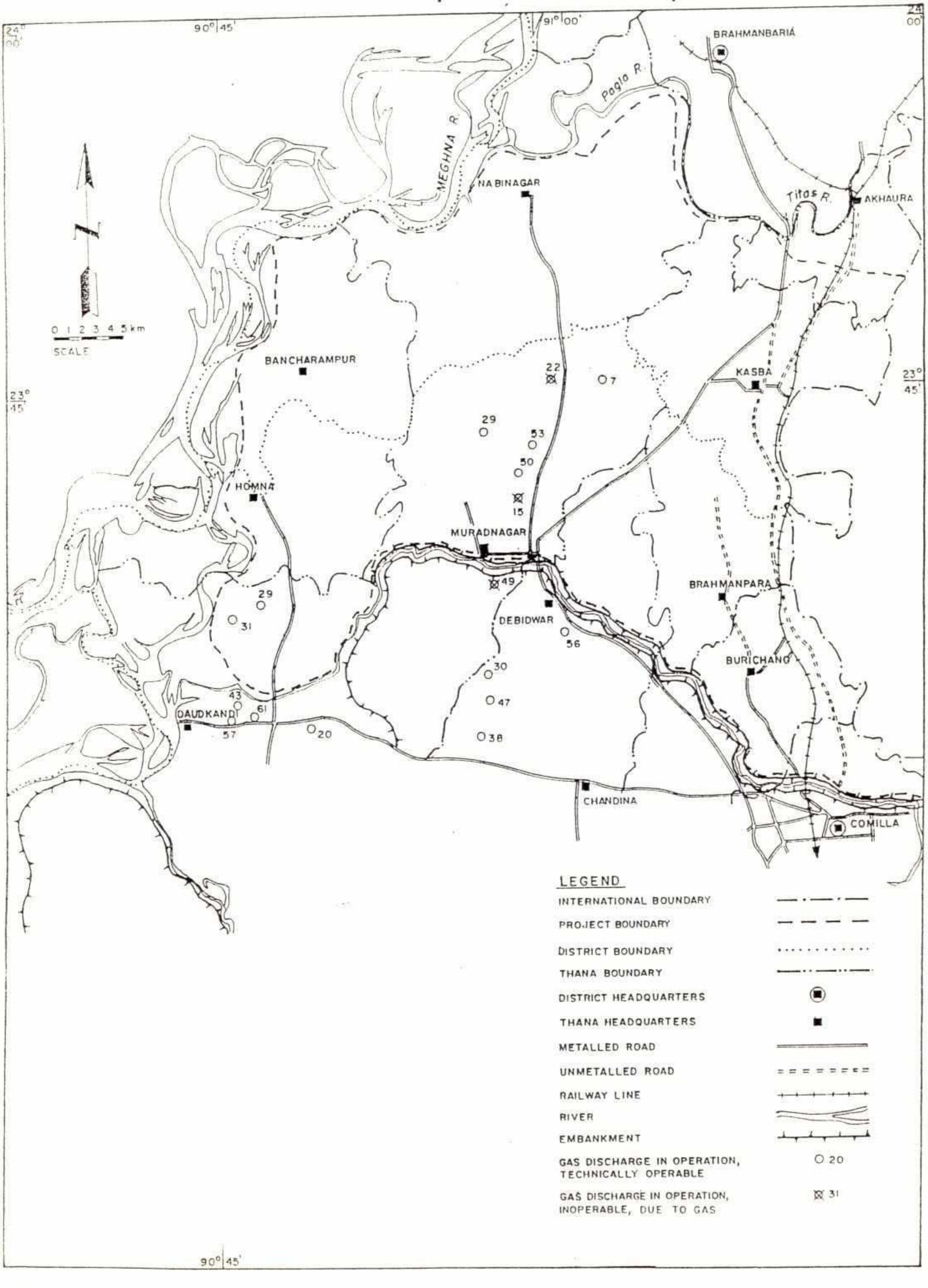
It is more difficult to quantify the constraint on STWs. However, there is no doubt that high speed, surface mounted suction pumps are inherently more susceptible to interference from gas discharges, which cause loss of suction. Interviews with BADC, BRDB and DAE officials, STW drillers, pump mechanics and farmers indicate serious problems in some areas. Indirect evidence is provided by the intensity of STW irrigation (see Figure C.I.2). It is seen that these areas closely coincide. Also the BADC STW inventory in 1987 showed that the areas of lowest STW intensity also had the highest rates of abandonment, indicating that STW irrigation was desired but found not feasible. The areas where STW development is constrained are shown in Figure C.I.2 based on discussion and on the spot visits to selected places as appended in Table C.I.2.

Gas in HTWs is extremely common, supporting the shallow origin of the gas, and as with DTWs is a nuisance but does not prevent the operation of wells. This is presumably due to the very slow operating speed of pump. Local people are generally aware where gas from hand tubewells can be ignited, these areas, if mapped, should be the same as those where STWs do not operate effectively, and offer a rapid reconnaissance method for examining other areas.

The distribution of gas occurrences in groundwater closely resembles that of salinity distribution in the main aquifer. This is probably explained by the high organic matter content of the upper part of the Chandina. Formation and perhaps especially so in the estuarine silts. This unfortunate combinantion locally results in areas where gas makes STWs impractical in the upper aquifer and salinity makes DTWs impractical in the lower aquifer.

Figure C.I.1

# Location of Deep Tubewells with Reported Gas Problems



# Figure C.I.2

## Gas Problems in Shallow Tubewells

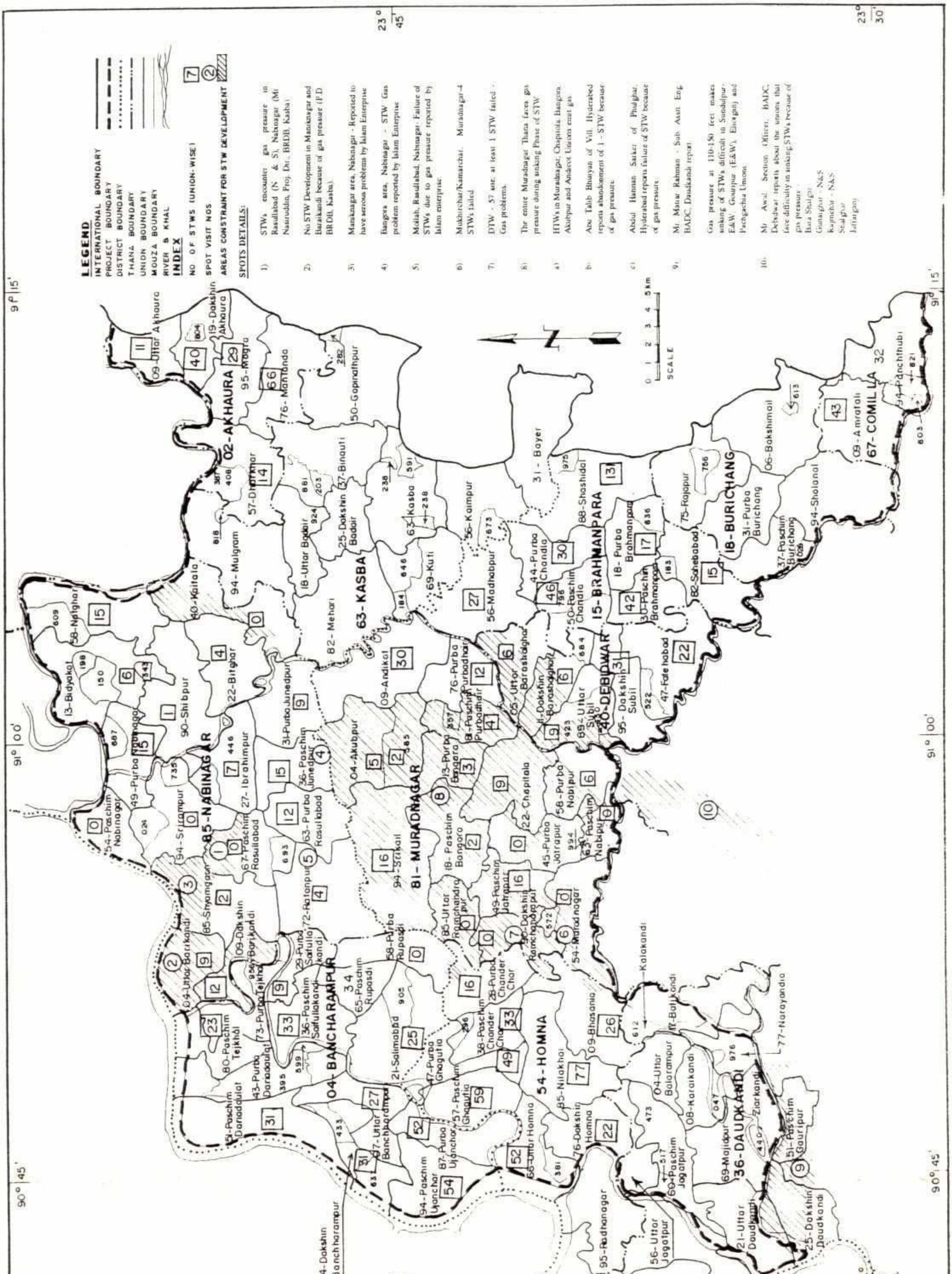


TABLE C.I.1

**Deep Tubewells with Reported Gas Problems in the Gumti Phase II and Adjoining Area**

| Thana | Union | DTW Nr | Nature of Problem | Remarks |
|---|---|---|---|---|
| Muradnagar | Andikot | 7 | Gas discharge in operation but technically operable. | |
| Muradnagar | Akubpur | 22 | No gas at commissioning, gas and low discharge since 1991. | Not operating since 1992. |
| Muradnagar | Bangara West | 29 | Gas emission, no discharge problem. | |
| Muradnagar | Chapitala | 50 | Normal discharge with gas emission and saline water. | Awaits decision on abandonment. |
| Muradnagar | Chapitala | 15 | Gas emission, not operable. | Abandoned. |
| Muradnagar | Bangara East | 53 | Gas discharge, technically operable. | |
| Muradnagar | Dhamghar | 49 | Gas emission, low discharge. | Abandoned for salinity (1992). |
| Daudkhandi | Daudkandi | 57 | Gas emission during discharge. | Peripheral to the project area. |
| Daudkhandi | Jagathpur South | 31 | Gas emission, but full discharge. | Not operating since 1991. |
| Daudkhandi | Daudkandi | 43 | Gas emission with yellowish, turbid water at commissioning; no gas or salinity problem now. | Peripheral to the project area. |
| Daudkhandi | Gouripur | 61 | Gas emission at commissioning; normal discharge and no gas now. | Peripheral to the project area. |
| Daudkhandi | Gouripur East | 20 | Gas emission and saline groundwater. | |
| Daudkhandi | Jagathpur North | 29 | Gas emission, low discharge | |
| Debidwar | Debidwar | 56 | Gas emission, regular discharge. | The DTW was resunk at a new site, discharge satisfactory but gas emission continues. |
| Debidwar | Rajmehar North | 47 | Gas emission (gas bubbles with water); less discharge (High iron content). | Iron problem (?) |
| Debidwar | Gunaighar | 30 | Gas emission, low discharge initially, noe OK (high iron). | Not operable. |
| Debidwar | Rajmehar (South) | 38 | Gas emission, low discharge. | |

TABLE C.I.2

Gas Discharge Survey
(October, 1992)

| Thana | | Persons Interviewed | | Description/Observations |
|---|---|---|---|---|
| Muradnagar | 1 | Mr. Sabbir Ahmad<br>Asstt. Engineer<br>Muradnagar | (a) | Provided particulars of DTWs showing reported gas problems. |
| | | | (b) | Reports that the BADC office has not much information about STW problems except that the STWs in Thana during sinking phase faced problem of gas pressure in the depth range of 150-200 ft. |
| | | | (c) | HTWs in Muradnagar, Chapitala, Bangora, Akubpur and Andicot unions emit gas. |
| | 2 | Mr. Abdul Jabbar<br>Sowdagar, BRDB,<br>Chairman, T.C.C.A<br>Muradnagar (Yusufnagar) | (a) | No gas emission in Mur-4 (DTW); abandoned because of high salinity; appeals to go beyond 2nd clay aquitard for fresh water. |
| | | | (b) | STWs in operation at Yusufnagar; gas pressure reported at the time of drilling; emits gas during discharge. |
| | | | (c) | HTWs emit gas |
| | 3 | Abdul Latif<br>Dhamghas(s) K.S.S.<br>Vill. & Union-Dhamghas | (a) | Reports that DTW No. Mur-7, Com. in 1990, had gas problem when started sinking in 1979; drilling could not be continued initially because of gas pressure. Drilling in 1989 under the IDA programme was successful; No gas discharge now. |
| | | | (b) | HTWs show gas bubbles; encountered gas pressure during sinking. |

| | | | |
|---|---|---|---|
| 4 | Abu Talib Bhuiyan<br>Vill. Hyderabad<br>Union: | (a) | Has 16 STWs with no gas emission. |
| | | (b) | Reports about gas problem in one STW, Com. in 1990. Continuous gas emission and then abandoned. The STW sunk about 100m away from the one mentioned shows no gas problem, suspects pocket gas. |
| | | (c) | No report of gas emission in the two DTWs located in the village. |
| 5 | Abdul Khaleq<br>Nohal K.S.S.<br>Dhamghas - Vill.<br>Union: | (a) | Report the case history of DTW Mur-7. Commissioned in 1991. No gas problem at the time of sinking in 1990. Discharge very well - 2.5 cusec; discharge at the time of commission interrupted because of gas emission. The DTW is abandoned and lifted in 1992. |
| | | (b) | HTWs show gas emission and gas pressure-encountered at depth ranging from 90 -150 feet . |
| 6 | Mr. Kabir Hossain<br>Sub. Asstt. Engineer<br>DPHE, Muradnagar | (a) | Gas emission in HTWs in Muradnagar, Kamela, Ramchandrapur (S. Union) - Harpakna and Pasketta villages. |
| | | (b) | Also reports a non-operating HTW in Nabinagar Thana (Vill. Dubachar, Khurshid Mia's residence) - gas bubbles. |
| 7 | Abdul Hannan Sarkar<br>Vill. Phulghar, Union -<br>Andikot | (a) | Reports that 15 STWs running well in Hyderabad village. |
| | | (b) | A STW in Vill. Phulghar faced difficulty during boring because of gas pressure. |
| | | (c) | A STW commissioned in 1990 was abandoned because of gas problem. |

8 Abdul Quddus Sarker, Mechanic, DPHE Muradnagar

(a) All HTWs sunk in the depth range of 90 -100 feet emit gas.

(b) Reports about gas emission in HTW - Muradnagar Kazi Bari, West side of Muradnagar Thana - HTW emits gas continuously-fire burns instanceously as soon as match stick is egnited accompanied with sound.

(c) Reports another case of gas emission at the house of Ershad Master, Vill. West Jangail, Akubpur Union: He was sinking a tube well (HTW) in 1974. People at one night heard a roaring sound (?) and found water with gas emission upto height of 15 feet. He withdrew one pipe (20 feet) and was gas emision was stopped. Presumed that aquifer materials at 90-100 feet depth was gas bearing and was under high pressure.

(e) Reports that the DTW at Raghunathpur, Homna (Hom-4) emits gas and a HTW at Raghunathpur Khandker Bari discharges saline ground water.

Nabinagar

| Persons Interview | | Observations |
|---|---|---|
| 1 Mr. Shah Alam<br>Executive Engineer<br>B. Baria | (a) | DTW No. Nab-21 at Bidyakut has salinity problem; no gas emission reported. |
| | (b) | DTW No. Nab-5 at Bariakandi is non operating due to both gas and salinity problem. |
| 2 Mr. Nasiruddin<br>Project Director,<br>BRDB, Kasba | (a) | In Rasullabad (N and S) Union - STWs encounter gas pressure |
| | (b) | No STW development in Maniknagar and Baraikandi because of gas pressure. |
| 3 Babul Sudangshu Shekhar<br>Sr. Sub. Asstt. Engineer<br>Nabinagar | (a) | DTW No. Nab-5 has salinity problem; did not run during the last irrigation season. |
| | (b) | DTW No. Na-30 has gas problems; at the time of test less discharge with gas emission (gas burns in the delivery pipe) - gas pressure and gas emission at 185 and 315 feet depth. The site was changed and no gas problem. DTW commissioned in 1991. |
| | (c) | DTW No. Nab-38 (Com. 1991-92) at Bitghar Union, Vill. Shibpur discharged yellowish turbid water (suspected gas) at the time of test; discharged well during 1992 irrigation season with good crop. |
| 4 Mr. Tofazzal Hossain<br>BRDB, Nabinagar | (a) | Reports about IDA/DTW No. Nab-42 at Naroi Brahmanhata K.S.S. Kaitola (Com. 22.2.92): After commissioning, discharged yellowish turbid water, probably associated with gas. Normal colour after 10 days. Discharging well, good crop. |
| | (b) | DTW No. Nab-5 at Baraikandi, Shyamgram, Vill. Kul Ashin (Com. 22/2/90): Saline ground water-crop damage; gear head broken Abandoned. |
| 5 Mr. Nurul Islam<br>Chairman, T.C.C.A | (a) | Serious Fe-problem in whole Thana, particularly in HTWs. |

**Daudkhandi**

| | Persons Interviewed | | Observation |
|---|---|---|---|
| 1 | Mr. Ershad. Sub. Asstt. Engineer Daudkandi | 1. | Reports problems with the following DTWs: |
| | | (a) | Daud - 61, Diapara K.S.S. JL 190, Plot - 1043 (Com. 25/6/91) : Discharge normal with emission of gas at the start, no gas after 1 hour. No problem detected in 1992 irrigation season. |
| | | (b) | Daud - 43, Motopi K.S.S. Majidpur, J.L. 222, Plot - 534. (Com. 15/01/1991): At start yellowish turbid water associated with gas; (fresh water after 1 hour). During 1992 irrigation season, gas emission but discharging well. |
| | | (c) | Daud - 31, Jagatpur - 5, Dashanip Para K.S.S. J.L - 209, Plot - 25-36 (26/01/1990-com.): Gas with water - functioned well in 1990 irrigation season. Non operating since 1991 primarily because of managerial problem but partly gas problem. |
| 2 | Mr. M. Matiar Rahman Sub. Asstt. Engineer, BADC, Daudkandi Unit-1 | (a) | Gas pressure at depth ranging from 110-120 feet makes sinking of STW difficult in the following unions:<br><br>Sundulpur (E&W)<br>Gouripur (E&W)<br>Mohammadpur<br>Eliotganj<br>Pachgachia |
| | | (b) | Describes the difficulties faced during sinking of STWs. Gas started encountering first at a depth of 30-40 feet: and then at 80 feet. Discharge of water interrupted because of gas bubbles and ultimately disrupted. Boring for STW in the west, East and North side of Vill. Mohammadpur (Sundulpur E Union), continued but could not be done because of gas pressure. Difficulty in sinking STWs faced on north side of Dhaka - Chittagong road. |
| | | (c) | DTW No. Daud-20: both saline and gas problem, but discharging well. |
| | | (d) | No STW in the neighbourshood of Daud-20 and Daud - 60 DTWs. |

Dehidwar

| | | Persons, Contacted | | Observation |
|---|---|---|---|---|
| 1 | | Md. Fashiur Reza<br>Foreman, BRDB | 1 | No failure of STW reported because of gas problem |
| 2 | | BRDB Weekly<br>Meeting (Wednesdays)<br>Central K.S.S,<br>Dehidwar | | |
| | (a) | Mr. Moslehuddin<br>Manager,<br>Purba Sangchail | (a) | DTW No. Deb-56 (IDA code No. 118/00705): Gas emission during testing stage. |
| | (b) | Mr. Kafiluddin<br>Manager<br>West Ballapur | (b) | No gas problem; crop damage due to Fe-content in the ground water. (DTW No. Deb-27, IDa Code No. 218/0076 |
| | (c) | Mr. Abdus Sattar,<br>Manager,<br>South Madhumura<br>K.S.S. | (c) | DTW No. Deb-30 (IDA) Code No. 219/00321)<br><br>Gas problem not noticeable, Fe-problem. |
| | (d) | Mr. Nityananda Das<br>South Saidpur K.S.S<br>Rajmehar | (d) | DTW No. Deb-38 (IDA Code 247/00061)<br><br>* Less discharge in 1990, no discharge in 1991-92, decision to be taken for abandonment.<br><br>* Gas emission with Fe-problem. |
| | (e) | Members,<br>Mollapara K.S.S<br>Rajmehar | (e) | DTW Deb-47, At the time of sinking gas emission, after resinking no problem. |
| | (f) | Member, Anantapur<br>K.S.S. | (f) | For Deb-27, gas emission, discharge not affected, no damage to crops |
| | (g) | Member, Sultanpur<br>K.S.S. | (g) | DTW No. Deb-39 (IDA Code No. 266/01027) Salinity problem. |
| 3 | | M. M. A. Awal<br>S/O, BADC<br>Dehidwar | 3 | The following Union/Villages face difficulty in sinking STW because of gas pressure:<br><br>Bara Shalghar<br>Gunaighar - N and S<br>Rajmehar - N and S<br>Shalghar<br>Jaffarganj<br><br>* Fe-problem in Elahabad Union. |

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**Kasba**

| Persons Interviewed | | Observations |
|---|---|---|
| 1 Md. Shafiqul Islam<br>Sr. Asstt. Sub Engineer,<br>Kasba | (a) | No gas problem in Kasba Thana except at the Bayek union (adj. to the Tripura foot hills). |
| | (b) | At Bayek union attempts were made for drilling (hand boring-water jetting); could not penetrate because of gas pressure beyound 150'. |
| | (c) | A DTW - Ka - 13 is non operating because of Village politics. |
| | (d) | Gas problem east of Kasba Rly line. |
| | (e) | The following DTWs face problems (not related to gas)<br>(I) Kaimpur - Ka-10 & Ka-69<br>Village Politics: 8-10 STWs Sunk around the DTWs.<br>(II) Kasba Union: Ka-20, Ka-127, Ka-131, Ka-16, and Ka-18:<br>Engine problem; no gas problem |
| | (f) | Conditions of DTWs in the following unions:<br>(I) Gopinthpur - Aquifer problem<br>(II) Binauti - DTWs and STWs running well<br>(III) Kuti - Aquifer problem, less discharge<br>(IV) Badiar (N&S) - No problem. |
| 2 Mr. Nasiruddin<br>Project Director,<br>BRDB, Kasba | (a) | No of DTWs - 55 (25 under IDA programme), No. of STW-33. |
| | (b) | Kuti Union: DTWs and STWs discharge less because of poor aquifer materials. |

**Burchang and Brahmanpara Thanas**

| Persons Interviewed | Observation |
|---|---|
| 1 Babu Amal Chandra Paul<br>Asstt. Engineer<br>Burichang-Brahmanpara | No Gas problem reported. |
| 2 Mr. Abdus Rashid Sarker<br>Asstt. Accountant | No gas problem reported |

**Comilla Kotwali Thana**

| Persons Interviewed | Observation |
|---|---|
| Mr. Mahbooh Monir<br>Asstt. Engineer<br>Kotwali | No gas emission problem reported either in DTWs or STWs. |

**Homna:**

| Persons Interviewed | | Observation |
|---|---|---|
| Mr. Ershad<br>Sub. Asstt. Engineer<br>incharge Homna | (a) | Provides particulars of the DTW operating in Homna. |

| DTW No. | Particulars | Yr. Com. |
|---|---|---|
| Homna-1 | Vill. Raghunathpur<br>JL 102, PI.430 | 21/11/1990 |
| Homna-2 | Homna N, Near<br>Homna Thana<br>JL 56, Plot 707 | 01/02/1992 |
| Homna-3 | Chandirchar K.S.S.,<br>Vill. Asadpur<br>JL-85, Plot-46 | 24/12/1991 |
| Homna-4 | Gopalnagar K.S.S.<br>JL-80, Plot 178 | 25/12/1991 |
| Homna-5 | Chandirchar K.S.S.<br>Chandirchar Vill.<br>PI-922, JL-97 | 27/02/1992 |

(b) DTW Homna-5 at Chandirchar (N) sunk in 1991 and commissioned in 1992; 2 cusec discharge at start, 1.5 cusec after 6 hours; Gas emission, less discharge believed to be due to gas discharge.

(c) No report of gas emission in the STWs.

**Bancharampur**

| Person interview | | Observations |
|---|---|---|
| 1 Mr. Shah Alam<br>Executive Engineer<br>Brahmanbaria | (a) | No gas problem reported |
| | (b) | DTW Nas-Banch-5 and banch-II at Rupashdi have acute salinity problem resulting in crop damage; Banch - 7 at Belanagas has salinity problem with crop damage. |

## Appendix C.II

## MINOR IRRIGATION STATISTICS

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Burichang | 1 Burichang | 8 | 263 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 263 | 265 |
| A | Burichang | 2 Januin | 8 | 208 | 3 | 14 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 223 | 227 |
| A | Burichang | 3 Jagatpur | 6 | 196 | 17 | 63 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 259 | 265 |
| A | Burichang | 4 Parnamati | 6 | 214 | 2 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 231 | 231 |
| A | Burichang | 5 Shampur | 3 | 73 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 6 | 121 | 0 | 0 | 130 | 73 | 202 |
| A | Burichang | 6 Jatrapur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 5 | 113 | 0 | 0 | 117 | 0 | 117 |
| A | Burichang | 7 Gobindapur | 1 | 40 | 2 | 16 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 6 | 162 | 0 | 0 | 166 | 57 | 223 |
| A | Burichang | 8 Bathangar | 5 | 137 | 1 | 5 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 142 | 158 |
| A | Burichang | 9 Rajpur | 7 | 263 | 20 | 101 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 364 | 364 |
| A | Burichang | 10 Shankuchail | 3 | 97 | 30 | 182 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 279 | 283 |
| A | Burichang | 11 Pachra | 4 | 162 | 43 | 225 | 1 | 10 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 397 | 405 |
| A | Burichang | 12 Bakshimul | 12 | 425 | 1 | 10 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 435 | 437 |
| A | Burichang | 13 Kalikapur | 3 | 57 | 4 | 32 | 0 | 0 | 0 | 0 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 53 | 89 | 142 |
| A | Burichang | 14 Ghota Horipur | 4 | 117 | 4 | 36 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 154 | 162 |
| A | Burichang | 15 Jamtala | 1 | 20 | 8 | 93 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 113 | 134 |
| A | Burichang | 16 Sholanal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 182 | 0 | 0 | 182 | 0 | 182 |
| A | Burichang | 17 Varashar | 7 | 172 | 0 | 0 | 2 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 184 | 184 |
| A | Burichang | 18 Purbahara | 2 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 113 | 0 | 0 | 113 | 53 | 166 |
| A | Burichang | 19 Kharataia | 5 | 178 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 180 | 180 |
| A | Burichang | 20 Shabrampur | 6 | 164 | 2 | 9 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 17 | 0 | 0 | 19 | 173 | 192 |
| **Totals** | | | **91** | **2,840** | **137** | **803** | **4** | **24** | **3** | **0** | **141** | **0** | **0** | **0** | **0** | **34** | **709** | **0** | **0** | **851** | **3,668** | **4,518** |

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Comilla | 15 Manipur | 5 | 97 | 6 | 34 | 2 | 10 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 142 | 152 |
| A | Comilla | 16 Amratali | 1 | 24 | 19 | 177 | 4 | 35 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 237 | 249 |
| A | Comilla | 17 Ratnabati | 5 | 144 | 4 | 28 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 45 | 0 | 0 | 47 | 172 | 219 |
| A | Comilla | 18 Rasulpur (Uttar) | 6 | 130 | 12 | 79 | 7 | 59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 267 | 267 |
| A | Comilla | 19 Rasulpur (Dakhl) | 1 | 28 | 2 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 212 | 0 | 0 | 212 | 36 | 249 |
| A | Comilla | 20 Kalikapur | 3 | 134 | 5 | 28 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 2 | 12 | 4 | 28 | 0 | 0 | 45 | 162 | 207 |
| A | Comilla | 21 Sharippur | 4 | 164 | 1 | 10 | 3 | 40 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 214 | 223 |
| A | Comilla | 22 Chaoulpur | 1 | 8 | 20 | 81 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 3 | 146 | 0 | 0 | 150 | 89 | 239 |
| A | Comilla | 23 Khirpur | 5 | 139 | 4 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 5 | 130 | 0 | 0 | 138 | 146 | 283 |
| A | Comilla | 24 Chanpur | 1 | 30 | 2 | 18 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 1 | 8 | 4 | 113 | 0 | 0 | 125 | 49 | 174 |
| A | Comilla | 28 Bibirbazar | 0 | 0 | 10 | 81 | 4 | 32 | 0 | 0 | 0 | 0 | 0 | 2 | 24 | 4 | 85 | 0 | 0 | 109 | 113 | 223 |
| **Totals** | | | **32** | **898** | **85** | **552** | **20** | **177** | **1** | **0** | **45** | **0** | **0** | **7** | **53** | **30** | **759** | **0** | **0** | **856** | **1,627** | **2,483** |

Data source : **AST/CIDA (1991)**, DAE

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Brahmanpara | 1 Madabpur | 2 | 53 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 55 | 0 | 0 | 55 | 57 | 111 |
| A | Brahmanpara | 2 Makimpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 65 | 0 | 0 | 4 | 81 | 2 | 57 | 202 | 0 | 202 |
| A | Brahmanpara | 3 Shaitshala | 2 | 69 | 4 | 32 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 61 | 0 | 0 | 0 | 0 | 63 | 101 | 164 |
| A | Brahmanpara | 4 Kandughar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A | Brahmanpara | 5 Jamtali | 0 | 0 | 10 | 61 | 0 | 0 | 0 | 0 | 10 | 4 | 8 | 0 | 0 | 20 | 162 | 0 | 0 | 180 | 61 | 241 |
| A | Brahmanpara | 6 Uttar Chandla | 1 | 32 | 12 | 121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 154 | 154 |
| A | Brahmanpara | 7 Shedlai | 4 | 73 | 14 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 3 | 119 | 121 |
| A | Brahmanpara | 8 Bera Khala | 1 | 19 | 32 | 215 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 235 | 235 |
| A | Brahmanpara | 9 Chandla | 5 | 132 | 6 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 180 | 180 |
| A | Brahmanpara | 10 Bara Dushia | 2 | 65 | 12 | 97 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 162 | 165 |
| A | Brahmanpara | 11 Dhalgram | 4 | 62 | 22 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 42 | 0 | 0 | 42 | 197 | 240 |
| A | Brahmanpara | 12 Nalla | 1 | 32 | 21 | 182 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 214 | 214 |
| A | Brahmanpara | 13 Dulalpur | 0 | 0 | 11 | 101 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 101 | 101 |
| A | Brahmanpara | 14 Gopashan nagar | 6 | 162 | 10 | 89 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 251 | 253 |
| A | Brahmanpara | 15 Naighar | 10 | 259 | 9 | 59 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 318 | 324 |
| A | Brahmanpara | 16 Bramanpara | 4 | 113 | 5 | 32 | 0 | 0 | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 146 | 174 |
| A | Brahmanpara | 17 Moha Lakshmipar | 5 | 115 | 3 | 21 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 136 | 142 |
| A | Brahmanpara | 18 Shehabadad | 9 | 283 | 6 | 45 | 0 | 0 | 0 | 0 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 | 328 | 368 |
| A | Brahmanpara | 19 Zeruin | 4 | 99 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 99 | 109 |
| A | Brahmanpara | 20 Chandipur | 3 | 85 | 6 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 121 | 0 | 0 | 121 | 121 | 243 |
| A | Brahmanpara | 21 Ramannagar | 0 | 0 | 3 | 16 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 2 | 6 | 0 | 0 | 0 | 0 | 14 | 16 | 30 |
| A | Brahmanpara | 22 Monoharpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 2 | 16 | 4 | 40 | 0 | 0 | 65 | 0 | 65 |
| A | Brahmanpara | 23 Tetaibumi | 0 | 0 | 24 | 223 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 223 | 223 |
| A | Brahmanpara | 24 Sashidal | 3 | 91 | 14 | 101 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 192 | 202 |
| A | Brahmanpara | 25 Bagra | 0 | 0 | 18 | 146 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 5 | 51 | 0 | 0 | 57 | 146 | 202 |
| A | Brahmanpara | 26 Deush | 0 | 0 | 37 | 235 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 8 | 2 | 32 | 0 | 0 | 42 | 235 | 277 |
| A | Brahmanpara | 27 Nagaish | 2 | 63 | 36 | 344 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 407 | 407 |
| **Totals** | | | **68** | **1,808** | **318** | **2,389** | **0** | **0** | **1** | **0** | **137** | **22** | **79** | **9** | **93** | **46** | **585** | **2** | **57** | **950** | **4,197** | **5,148** |

Data source : AST/CIDA (1991), DAE

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Debidwar | 1 Barashalaghar | 1 | 32 | 1 | 7 | 0 | 0 | 0 | 0 | 40 | 0 | 0 | 1 | 8 | 7 | 140 | 0 | 0 | 188 | 39 | 227 |
| A | Debidwar | 2 Prajapati | 3 | 36 | 5 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 61 | 61 |
| A | Debidwar | 3 Sangpail | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 2 | 14 | 1 | 21 | 0 | 0 | 43 | 0 | 43 |
| A | Debidwar | 4 Echabpur | 0 | 0 | 2 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 1 | 10 | 0 | 0 | 14 | 16 | 30 |
| A | Debidwar | 5 Maheshpur | 0 | 0 | 3 | 6 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 9 |
| A | Debidwar | 6 Mugshair | 1 | 28 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34 | 34 |
| A | Debidwar | 7 Gopalnagar | 0 | 0 | 1 | 6 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 4 | 38 | 0 | 0 | 45 | 6 | 51 |
| A | Debidwar | 8 Gopalpur | 0 | 0 | 3 | 8 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 5 | 83 | 0 | 0 | 87 | 8 | 95 |
| A | Debidwar | 9 Rasulpur | 2 | 45 | 5 | 29 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 45 | 2 | 81 | 127 | 74 | 201 |
| A | Debidwar | 10 Wahedpur | 0 | 0 | 7 | 53 | 0 | 0 | 0 | 0 | 20 | 1 | 0 | 9 | 40 | 1 | 8 | 0 | 0 | 69 | 53 | 122 |
| A | Debidwar | 11 Burirpar | 0 | 0 | 5 | 40 | 0 | 0 | 0 | 0 | 36 | 2 | 4 | 1 | 6 | 0 | 0 | 0 | 0 | 47 | 40 | 87 |
| A | Debidwar | 12 Subil | 0 | 0 | 19 | 55 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 55 | 75 |
| A | Debidwar | 19 Fathabad | 0 | 0 | 18 | 79 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 10 | 0 | 0 | 0 | 0 | 12 | 79 | 91 |
| A | Debidwar | 20 Sultanpur | 0 | 0 | 25 | 132 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 32 | 0 | 0 | 32 | 132 | 164 |
| A | Debidwar | 21 Maichapara | 0 | 0 | 37 | 164 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 164 | 164 |
| A | Debidwar | 22 Chanpur | 0 | 0 | 8 | 61 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 81 | 0 | 0 | 83 | 61 | 144 |
| A | Debidwar | 23 Khalidpur | 0 | 0 | 10 | 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 142 | 0 | 0 | 142 | 55 | 196 |
| A | Debidwar | 24 Kotnanurpur | 0 | 0 | 24 | 71 | 0 | 0 | 0 | 0 | 6 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 71 | 81 |
| **Totals** | | | **7** | **141** | **174** | **811** | **0** | **0** | **0** | **0** | **147** | **6** | **12** | **16** | **83** | **30** | **600** | **2** | **81** | **924** | **952** | **1,875** |

Data source : AST/CIDA (1991), DAE

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | Kasba | 1 Shahpur | 7 | 174 | 24 | 196 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 370 | 370 |
| B | Kasba | 2 Taltala | 3 | 111 | 15 | 150 | 0 | 0 | 0 | 0 | 0 | 3 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 261 | 281 |
| B | Kasba | 3 Charnal | 3 | 51 | 7 | 40 | 0 | 0 | 5 | 2 | 77 | 0 | 0 | 2 | 8 | 0 | 0 | 0 | 0 | 85 | 93 | 178 |
| B | Kasba | 4 Kashba block | 1 | 12 | 10 | 93 | 0 | 0 | 5 | 2 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 107 | 121 |
| B | Kasba | 5 Akchina | 5 | 134 | 32 | 210 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 344 | 348 |
| B | Kasba | 6 Zazishar | 0 | 0 | 19 | 130 | 0 | 0 | 0 | 0 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 83 | 130 | 212 |
| B | Kasba | 7 Mainpur | 0 | 0 | 26 | 172 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 1 | 6 | 10 | 172 | 0 | 0 | 188 | 172 | 360 |
| B | Kasba | 8 Kamalpur | 2 | 49 | 30 | 190 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 3 | 69 | 0 | 0 | 73 | 239 | 312 |
| B | Kasba | 9 Baik | 0 | 0 | 5 | 30 | 0 | 0 | 0 | 0 | 18 | 1 | 4 | 3 | 36 | 20 | 356 | 0 | 0 | 415 | 30 | 445 |
| B | Kasba | 10 Kullapathar | 0 | 0 | 4 | 40 | 0 | 0 | 0 | 0 | 174 | 0 | 0 | 0 | 0 | 15 | 162 | 0 | 0 | 336 | 40 | 376 |
| B | Kasba | 11 Madla | 0 | 0 | 7 | 53 | 0 | 0 | 0 | 0 | 304 | 0 | 0 | 0 | 0 | 13 | 190 | 0 | 0 | 494 | 53 | 546 |
| B | Kasba | 12 Kuti | 1 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 28 | 5 | 158 | 0 | 0 | 186 | 36 | 223 |
| B | Kasba | 13 Jagiara | 0 | 0 | 11 | 89 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 16 | 5 | 130 | 0 | 0 | 146 | 89 | 235 |
| B | Kasba | 14 Lemiara | 5 | 243 | 25 | 148 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 391 | 391 |
| B | Kasba | 15 Maijkhar | 3 | 125 | 6 | 81 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 7 | 97 | 0 | 0 | 0 | 0 | 101 | 206 | 308 |
| B | Kasba | 16 Jamsherpur | 2 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 32 |
| B | Kasba | 17 Mandarpur | 2 | 47 | 2 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 59 | 59 |
| B | Kasba | 18 Badhair | 7 | 160 | 7 | 40 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 200 | 202 |
| B | Kasba | 19 Kherara | 5 | 101 | 13 | 123 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 225 | 227 |
| B | Kasba | 20 Sonagaon | 4 | 57 | 4 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 79 | 79 |
| B | Kasba | 21 Dheli | 2 | 28 | 5 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51 | 51 |
| B | Kasba | 22 Simrail | 2 | 47 | 12 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 40 | 24 | 415 | 0 | 0 | 455 | 134 | 589 |
| B | Kasba | 23 Mehari | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 20 | 0 | 0 | 0 | 0 | 20 | 0 | 20 |
| B | Kasba | 24 Kheora | 1 | 28 | 7 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 93 | 93 |
| B | Kasba | 25 Choaibapur | 4 | 79 | 5 | 36 | 0 | 0 | 0 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 115 | 134 |
| B | Kasba | 26 Binauti | 4 | 40 | 10 | 47 | 0 | 0 | 0 | 0 | 168 | 0 | 0 | 3 | 20 | 9 | 109 | 0 | 0 | 297 | 87 | 384 |
| B | Kasba | 27 Saiadabad | 9 | 212 | 15 | 79 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 4 | 24 | 6 | 69 | 0 | 0 | 97 | 291 | 389 |
| B | Kasba | 28 Tigharia | 1 | 8 | 13 | 45 | 0 | 0 | 10 | 6 | 20 | 4 | 8 | 7 | 32 | 4 | 45 | 0 | 0 | 105 | 59 | 164 |
| B | Kasba | 29 Gopinathpur | 0 | 0 | 22 | 63 | 0 | 0 | 25 | 30 | 152 | 0 | 0 | 4 | 32 | 3 | 36 | 0 | 0 | 221 | 93 | 314 |
| B | Kasba | 30 Chandidar | 1 | 20 | 16 | 71 | 0 | 0 | 10 | 12 | 75 | 0 | 0 | 0 | 0 | 1 | 14 | 0 | 0 | 89 | 103 | 192 |
| B | Kasba | 31 Rajnagar | 0 | 0 | 29 | 146 | 0 | 0 | 0 | 0 | 69 | 0 | 0 | 0 | 0 | 1 | 8 | 0 | 0 | 77 | 146 | 223 |
| B | Kasba | 32 Bishunagar | 0 | 0 | 13 | 81 | 0 | 0 | 0 | 0 | 198 | 0 | 0 | 0 | 0 | 12 | 101 | 0 | 0 | 299 | 81 | 380 |
| B | Kasba | 33 Mulgram | 6 | 138 | 0 | 0 | 0 | 0 | 0 | 0 | 42 | 0 | 0 | 2 | 12 | 0 | 0 | 1 | 283 | 338 | 138 | 476 |
| B | Kasba | 34 Shambari | 5 | 81 | 4 | 32 | 0 | 0 | 0 | 0 | 81 | 0 | 0 | 5 | 81 | 0 | 0 | 0 | 0 | 162 | 113 | 275 |
| B | Kasba | 35 Chargach | 5 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 170 | 170 |
| B | Kasba | 36 Niamatpur | 2 | 57 | 3 | 20 | 0 | 0 | 0 | 0 | 109 | 0 | 0 | 2 | 32 | 2 | 61 | 0 | 0 | 202 | 77 | 279 |
| **Totals** | | | **92** | **2,240** | **401** | **2,614** | **0** | **0** | **55** | **53** | **1,633** | **8** | **32** | **52** | **488** | **133** | **2,094** | **1** | **283** | **4,531** | **4,907** | 9,437 |

Data source : AST/CIDA (1991), DAE

Appendix C.II

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | Akhaura | 1 Kharkut | 0 | 0 | 2 | 4 | 0 | 0 | 0 | 0 | 204 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 204 | 4 | 208 |
| B | Akhaura | 5 Mariand | 0 | 0 | 24 | 113 | 0 | 0 | 5 | 1 | 139 | 2 | 2 | 8 | 36 | 4 | 53 | 0 | 0 | 230 | 114 | 344 |
| B | Akhaura | 10 Chatuya | 7 | 227 | 17 | 79 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 15 | 146 | 0 | 0 | 150 | 306 | 455 |
| B | Akhaura | 11 Bara Louhaghar | 0 | 0 | 4 | 19 | 0 | 0 | 0 | 0 | 234 | 0 | 0 | 1 | 4 | 1 | 18 | 0 | 0 | 257 | 19 | 275 |
| B | Akhaura | 12 Kholkhar | 6 | 59 | 22 | 198 | 0 | 0 | 0 | 0 | 28 | 0 | 0 | 1 | 12 | 10 | 109 | 0 | 0 | 150 | 257 | 407 |
| B | Akhaura | 13 Ruti | 2 | 69 | 25 | 144 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 1 | 16 | 10 | 119 | 0 | 0 | 148 | 212 | 361 |
| B | Akhaura | 18 Dharmagar | 0 | 0 | 6 | 89 | 0 | 0 | 5 | 1 | 45 | 4 | 4 | 4 | 38 | 0 | 0 | 0 | 0 | 86 | 90 | 176 |
| **Totals** | | | **15** | **355** | **100** | **645** | **0** | **0** | **10** | **2** | **667** | **6** | **6** | **15** | **106** | **40** | **445** | **0** | **0** | **1,225** | **1,002** | **2,227** |

Data source : AST/CIDA (1991), DAE

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Muradnagar | 1 Srikail | 1 | 38 | 7 | 40 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 79 | 81 |
| C | Muradnagar | 2 Chandanail | 2 | 59 | 0 | 0 | 0 | 0 | 10 | 2 | 1 | 0 | 0 | 0 | 0 | 2 | 20 | 0 | 0 | 21 | 61 | 82 |
| C | Muradnagar | 3 Pipria Kanda | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 6 | 117 | 0 | 0 | 118 | 0 | 118 |
| C | Muradnagar | 4 Roa Chala | 0 | 0 | 9 | 57 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 57 | 61 |
| C | Muradnagar | 5 Akubpur | 2 | 45 | 5 | 53 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 97 | 98 |
| C | Muradnagar | 6 Balighar | 1 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 22 |
| C | Muradnagar | 7 Metang Ghar | 3 | 71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71 | 71 |
| C | Muradnagar | 8 Peen Kashimpur | 4 | 83 | 2 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 100 |
| C | Muradnagar | 9 Andikut | 0 | 0 | 4 | 40 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 2 | 16 | 4 | 40 | 0 | 0 | 61 | 40 | 101 |
| C | Muradnagar | 10 Haidrabad | 2 | 49 | 20 | 162 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 4 | 73 | 0 | 0 | 93 | 210 | 304 |
| C | Muradnagar | 11 Jerara | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 3 | 51 | 0 | 0 | 63 | 0 | 63 |
| C | Muradnagar | 12 Dalfa | 0 | 0 | 1 | 10 | 0 | 0 | 0 | 0 | 20 | 1 | 1 | 0 | 0 | 6 | 149 | 0 | 0 | 170 | 10 | 180 |
| C | Muradnagar | 13 Dewra | 0 | 0 | 5 | 85 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 7 | 117 | 0 | 0 | 130 | 85 | 214 |
| C | Muradnagar | 14 Khoshghar | 1 | 24 | 9 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 57 | 7 | 219 | 0 | 0 | 275 | 130 | 405 |
| C | Muradnagar | 15 Kurbanpur | 1 | 30 | 3 | 30 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 12 | 0 | 0 | 0 | 0 | 13 | 61 | 74 |
| C | Muradnagar | 16 Nabiabad | 3 | 75 | 4 | 37 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 1 | 28 | 0 | 0 | 40 | 112 | 153 |
| C | Muradnagar | 17 Moheshpur | 2 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 45 | 0 | 0 | 45 | 6 | 51 |
| C | Muradnagar | 18 Bangara | 4 | 107 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 107 | 108 |
| C | Muradnagar | 19 Daulatpur | 3 | 93 | 3 | 24 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 117 | 123 |
| C | Muradnagar | 20 Pushkarinirpar | 0 | 0 | 2 | 10 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 10 | 13 |
| C | Muradnagar | 21 Baira | 2 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 101 | 1 | 40 | 142 | 45 | 186 |
| C | Muradnagar | 22 Tashki | 1 | 45 | 3 | 22 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 67 | 81 |
| C | Muradnagar | 23 Chapitala | 5 | 202 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 202 | 202 |
| C | Muradnagar | 24 Jamalpur | 2 | 85 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 38 | 0 | 0 | 38 | 91 | 130 |
| C | Muradnagar | 25 Jatrapur | 3 | 69 | 5 | 40 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 5 | 192 | 0 | 0 | 0 | 0 | 214 | 109 | 324 |
| C | Muradnagar | 26 Mochagara | 1 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 10 | 0 | 0 | 0 | 0 | 11 | 27 | 38 |
| C | Muradnagar | 27 Noagaon | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 10 | 9 | 173 | 0 | 0 | 184 | 0 | 184 |
| C | Muradnagar | 28 Kamalla | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 0 | 0 | 10 | 87 | 0 | 0 | 0 | 0 | 88 | 3 | 91 |
| C | Muradnagar | 29 Kalipur | 0 | 0 | 7 | 42 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 42 | 47 |
| C | Muradnagar | 30 Dhanapati Khola | 1 | 24 | 9 | 44 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 20 | 0 | 0 | 21 | 68 | 89 |
| C | Muradnagar | 31 Ramchandapur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 142 | 0 | 0 | 142 | 0 | 142 |
| C | Muradnagar | 32 Bra Chapitala | 1 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 16 |
| C | Muradnagar | 33 Panch Kitta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 13 | 123 | 0 | 0 | 130 | 0 | 130 |
| C | Muradnagar | 34 Digaldi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 1 | 6 | 11 | 138 | 0 | 0 | 154 | 0 | 154 |
| C | Muradnagar | 35 Muradnagar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 8 | 174 | 1 | 61 | 243 | 0 | 243 |
| C | Muradnagar | 36 Madayanagar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 0 | 1 | 8 | 9 | 121 | 0 | 0 | 148 | 0 | 148 |
| C | Muradnagar | 37 Dhaniranapur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 6 | 45 | 12 | 181 | 1 | 59 | 287 | 0 | 287 |
| C | Muradnagar | 38 Alirchar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 16 | 9 | 160 | 0 | 0 | 177 | 0 | 177 |
| C | Muradnagar | 39 Gungar | 1 | 49 | 1 | 8 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 16 | 259 | 0 | 0 | 267 | 57 | 324 |
| C | Muradnagar | 40 Bakharnagar | 4 | 103 | 5 | 19 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 122 | 126 |
| C | Muradnagar | 41 Companiganj | 1 | 19 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 8 | 6 | 131 | 0 | 0 | 141 | 19 | 161 |
| C | Muradnagar | 42 Rahimpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 1 | 2 | 0 | 0 | 10 | 344 | 0 | 0 | 356 | 0 | 356 |
| **Totals** | | | **51** | **1,385** | **105** | **852** | **0** | **0** | **14** | **5** | **206** | **4** | **6** | **38** | **476** | **168** | **2,965** | **3** | **160** | **3,813** | **2,242** | **6,055** |

Data source : AST/CIDA (1991), DAE

Appendix C.II

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Nabinagar | 1 Ibrahimpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 2 | 10 | 15 | 330 | 0 | 0 | 344 | 0 | 344 |
| C | Nabinagar | 2 Bholachang | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 1 | 1 | 1 | 10 | 7 | 92 | 0 | 0 | 121 | 0 | 121 |
| C | Nabinagar | 3 Dolabari | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 3 | 30 | 4 | 95 | 0 | 0 | 132 | 0 | 132 |
| C | Nabinagar | 4 Natghar | 0 | 0 | 2 | 16 | 0 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 0 | 12 | 275 | 0 | 0 | 306 | 16 | 322 |
| C | Nabinagar | 5 Kurigram | 0 | 0 | 8 | 97 | 0 | 0 | 0 | 0 | 18 | 2 | 24 | 16 | 291 | 0 | 0 | 0 | 0 | 334 | 97 | 431 |
| C | Nabinagar | 6 Khariwala | 0 | 0 | 14 | 142 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 4 | 40 | 8 | 178 | 0 | 0 | 239 | 142 | 380 |
| D | Nabinagar | 11 Barikandi | 0 | 0 | 3 | 14 | 0 | 0 | 20 | 8 | 69 | 0 | 0 | 1 | 10 | 2 | 18 | 0 | 0 | 97 | 22 | 119 |
| D | Nabinagar | 12 Nurjahanpur | 0 | 0 | 3 | 24 | 0 | 0 | 7 | 6 | 109 | 3 | 24 | 1 | 9 | 1 | 12 | 0 | 0 | 155 | 30 | 185 |
| C | Nabinagar | 13 Rasullabad | 2 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 2 | 26 | 2 | 40 | 0 | 0 | 73 | 8 | 81 |
| C | Nabinagar | 14 Molla | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | Nabinagar | 15 Urkhulia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 2 | 4 | 11 | 121 | 9 | 180 | 0 | 0 | 334 | 0 | 334 |
| C | Nabinagar | 16 Bidhaya Kut | 2 | 24 | 13 | 73 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 14 | 231 | 0 | 0 | 231 | 97 | 329 |
| C | Nabinagar | 17 Merkuta | 2 | 20 | 2 | 16 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 6 | 87 | 0 | 0 | 91 | 36 | 127 |
| C | Nabinagar | 18 Bhairabnagar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 6 | 69 | 7 | 142 | 0 | 0 | 222 | 0 | 222 |
| C | Nabinagar | 19 Fathapur | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 101 | 0 | 0 | 101 | 4 | 105 |
| C | Nabinagar | 20 Hajipur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 10 | 13 | 192 | 0 | 0 | 202 | 0 | 202 |
| B | Nabinagar | 21 Mohishpur | 1 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 14 | 49 | 2 | 36 | 16 | 312 | 0 | 0 | 405 | 49 | 453 |
| B | Nabinagar | 22 Bitghar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 1 | 4 | 0 | 0 | 8 | 178 | 0 | 0 | 198 | 0 | 198 |
| B | Nabinagar | 23 Gurigram | 2 | 77 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 2 | 16 | 0 | 0 | 0 | 0 | 28 | 77 | 105 |
| B | Nabinagar | 24 Tiara | 1 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 28 | 32 |
| C | Nabinagar | 25 Ratanpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 12 | 0 | 0 | 0 | 0 | 12 | 0 | 12 |
| C | Nabinagar | 26 Majiara | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 6 | 61 | 2 | 20 | 0 | 0 | 0 | 0 | 85 | 0 | 85 |
| C | Nabinagar | 27 Sahapur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 65 | 0 | 0 | 65 | 0 | 65 |
| C | Nabinagar | 31 Moholla | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 49 | 7 | 20 | 16 | 162 | 14 | 291 | 0 | 0 | 522 | 4 | 526 |
| C | Nabinagar | 32 Nabinagar | 1 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 10 | 202 | 0 | 0 | 223 | 14 | 237 |
| C | Nabinagar | 33 Bagjar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 29 | 599 | 0 | 0 | 607 | 0 | 607 |
| C | Nabinagar | 34 Srirampur | 4 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 9 | 243 | 0 | 0 | 245 | 83 | 328 |
| C | Nabinagar | 35 Naraynpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 13 | 277 | 1 | 40 | 324 | 0 | 324 |
| C | Nabinagar | 36 Alamnagar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 10 | 224 | 0 | 0 | 235 | 0 | 235 |
| C | Nabinagar | 37 Gopalnagar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 11 | 219 | 0 | 0 | 247 | 0 | 247 |
| C | Nabinagar | 41 Shaharpar | 1 | 5 | 4 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 22 |
| C | Nabinagar | 42 Kanikara | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 4 | 8 | 1 | 2 | 9 | 81 | 18 | 256 | 0 | 0 | 347 | 4 | 351 |
| C | Nabinagar | 43 Baghaura | 2 | 36 | 3 | 24 | 0 | 0 | 0 | 0 | 1 | 1 | 8 | 4 | 49 | 4 | 73 | 0 | 0 | 130 | 61 | 191 |
| C | Nabinagar | 44 Shibpur | 0 | 0 | 12 | 36 | 0 | 0 | 0 | 0 | 12 | 1 | 5 | 3 | 36 | 11 | 186 | 0 | 0 | 240 | 36 | 276 |
| D | Nabinagar | 45 Shamgram | 1 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 1 | 16 | 4 | 93 | 0 | 0 | 125 | 16 | 142 |
| D | Nabinagar | 46 Sahabajpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 263 | 0 | 0 | 263 | 0 | 263 |
| D | Nabinagar | 47 Jallikandi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 40 | 0 | 0 | 40 | 0 | 40 |
| C | Nabinagar | 48 Jinadpur | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 | 7 | 0 | 0 | 0 | 0 | 10 | 2 | 12 |
| C | Nabinagar | 49 Bangara | 1 | 14 | 1 | 6 | 0 | 0 | 0 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 20 | 24 |
| B | Nabinagar | 50 Bramanhata | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 16 | 115 | 9 | 223 | 0 | 0 | 352 | 0 | 352 |
| C | Nabinagar | 51 Konaura | 2 | 61 | 2 | 53 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 113 | 121 |
| C | Nabinagar | 52 Kaitala | 1 | 38 | 7 | 93 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 9 | 198 | 0 | 0 | 204 | 132 | 336 |
| B | Nabinagar | 53 Noagaon | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 4 | 38 | 6 | 105 | 25 | 302 | 0 | 0 | 457 | 0 | 457 |

Data source : AST/CIDA (1991), DAE

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D | Nabinagar | 54 Salimganj | 0 | 0 | 2 | 3 | 0 | 0 | 5 | 1 | 1 | 4 | 13 | 1 | 6 | 11 | 188 | 0 | 0 | 209 | 4 | 212 |
| D | Nabinagar | 55 Char Badda | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 4 | 40 | 0 | 0 | 51 | 0 | 51 |
| C | Nabinagar | 59 Nabipur | 1 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 51 | 0 | 0 | 4 | 40 | 6 | 81 | 0 | 0 | 172 | 22 | 194 |
| C | Nabinagar | 60 Charlapang | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 4 | 49 | 0 | 0 | 4 | 81 | 0 | 0 | 150 | 0 | 150 |
| C | Nabinagar | 61 Satepur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 0 | 0 | 1 | 8 | 11 | 151 | 0 | 0 | 191 | 0 | 191 |
| C | Nabinagar | 62 Satmora | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 5 | 0 | 0 | 0 | 0 | 2 | 10 | 0 | 0 | 15 | 5 | 20 |
| C | Nabinagar | 63 Chudria | 2 | 34 | 3 | 24 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 59 | 61 |
| **Totals** | | | **27** | **535** | **81** | **645** | **0** | **0** | **40** | **24** | **677** | **54** | **311** | **122** | **1,354** | **360** | **6,769** | **1** | **40** | **9,152** | **1,204** | **10,356** |

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Data source : AST/CIDA (1991), DAE

Appendix C.II

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D | Daudkandi | 1 Bara Laksmipur | 0 | 0 | 5 | 34 | 0 | 0 | 20 | 6 | 4 | 0 | 0 | 17 | 123 | 0 | 0 | 0 | 0 | 127 | 40 | 168 |
| D | Daudkandi | 2 Bara Kanda | 0 | 0 | 11 | 53 | 0 | 0 | 20 | 10 | 4 | 0 | 0 | 10 | 101 | 0 | 0 | 0 | 0 | 105 | 63 | 168 |
| D | Daudkandi | 3 Mohammedpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 6 | 73 | 8 | 105 | 0 | 0 | 181 | 0 | 181 |
| D | Daudkandi | 4 Char Pakhalia | 0 | 0 | 3 | 19 | 0 | 0 | 15 | 4 | 8 | 0 | 0 | 5 | 97 | 2 | 34 | 0 | 0 | 140 | 23 | 163 |
| D | Daudkandi | 5 Sonarchar | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 8 | 20 | 0 | 0 | 0 | 0 | 12 | 154 | 0 | 0 | 174 | 8 | 182 |
| D | Daudkandi | 6 Kalai Gobindapu | 0 | 0 | 12 | 101 | 0 | 0 | 25 | 10 | 20 | 0 | 0 | 2 | 16 | 0 | 0 | 0 | 0 | 36 | 111 | 148 |
| D | Daudkandi | 7 Batakandi | 2 | 42 | 4 | 49 | 0 | 0 | 4 | 1 | 8 | 0 | 0 | 0 | 0 | 4 | 73 | 0 | 0 | 81 | 92 | 173 |
| D | Daudkandi | 8 Gagatpur | 2 | 45 | 3 | 36 | 0 | 0 | 2 | 0 | 6 | 0 | 0 | 0 | 0 | 5 | 81 | 0 | 0 | 87 | 81 | 168 |
| D | Daudkandi | 9 Krishnawpur | 2 | 34 | 7 | 48 | 0 | 0 | 15 | 6 | 24 | 0 | 0 | 4 | 49 | 2 | 28 | 0 | 0 | 101 | 89 | 190 |
| D | Daudkandi | 10 Char Kumaria | 1 | 16 | 6 | 40 | 0 | 0 | 5 | 1 | 1 | 0 | 0 | 0 | 0 | 5 | 65 | 0 | 0 | 66 | 57 | 123 |
| D | Daudkandi | 11 Balarampur | 3 | 40 | 14 | 105 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 16 | 0 | 0 | 0 | 0 | 18 | 146 | 164 |
| D | Daudkandi | 12 Bandarampur | 0 | 0 | 13 | 81 | 0 | 0 | 100 | 12 | 4 | 0 | 0 | 0 | 0 | 18 | 239 | 0 | 0 | 243 | 93 | 336 |
| D | Daudkandi | 13 Kari Kandi | 1 | 8 | 14 | 64 | 0 | 0 | 1 | 1 | 121 | 1 | 2 | 0 | 0 | 3 | 28 | 0 | 0 | 152 | 72 | 224 |
| D | Daudkandi | 16 Kalachand Kandi | 0 | 0 | 6 | 45 | 0 | 0 | 5 | 2 | 63 | 1 | 2 | 2 | 14 | 11 | 109 | 0 | 0 | 189 | 46 | 235 |
| D | Daudkandi | 17 Dari Kandi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 6 | 52 | 13 | 285 | 1 | 40 | 385 | 0 | 385 |
| D | Daudkandi | 18 Kadamtali | 0 | 0 | 7 | 71 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 13 | 172 | 0 | 0 | 176 | 71 | 247 |
| D | Daudkandi | 19 Gopalpur | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 6 | 4 | 0 | 0 | 4 | 47 | 14 | 293 | 0 | 0 | 344 | 6 | 350 |
| D | Daudkandi | 20 Asmania | 0 | 0 | 11 | 81 | 0 | 0 | 10 | 3 | 5 | 0 | 0 | 0 | 0 | 11 | 125 | 0 | 0 | 130 | 84 | 215 |
| D | Daudkandi | 21 North Narandia | 0 | 0 | 15 | 115 | 0 | 0 | 4 | 2 | 15 | 0 | 0 | 7 | 77 | 0 | 0 | 1 | 121 | 213 | 117 | 330 |
| D | Daudkandi | 22 Mohanpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10 | 69 | 15 | 170 | 0 | 0 | 240 | 0 | 240 |
| D | Daudkandi | 23 Motupi Shibpur | 2 | 49 | 4 | 40 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 14 | 182 | 0 | 0 | 190 | 89 | 279 |
| D | Daudkandi | 24 Majidpur | 0 | 0 | 8 | 67 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 14 | 115 | 3 | 42 | 0 | 0 | 162 | 67 | 229 |
| D | Daudkandi | 25 Lalpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 6 | 47 | 12 | 202 | 0 | 0 | 263 | 0 | 263 |
| D | Daudkandi | 26 Chenga Kandi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 8 | 47 | 16 | 206 | 0 | 0 | 257 | 0 | 257 |
| D | Daudkandi | 27 Hasnabad | 0 | 0 | 6 | 36 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 5 | 30 | 19 | 263 | 0 | 0 | 306 | 36 | 342 |
| D | Daudkandi | 28 Baharchar | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 8 | 40 | 11 | 194 | 0 | 0 | 243 | 4 | 247 |
| **Totals** | | | **13** | **235** | **150** | **1,090** | **0** | **0** | **280** | **72** | **376** | **2** | **4** | **116** | **1,014** | **211** | **3,052** | **2** | **162** | **4,608** | **1,397** | **6,005** |

Data source : AST/CIDA (1991), DAE

Appendix C.II

| Zone | Thana Name | Block Nr & Name | DTW Nr | DTW (ha) | STW Nr | STW (ha) | DSSTW Nr | DSSTW (ha) | MTW Nr | MTW (ha) | Traditional Irrigation (ha) | LLP < 1.0cusec Nr | LLP < 1.0cusec (ha) | LLP 1.0 cusec Nr | LLP 1.0 cusec (ha) | LLP 2 cs Nr | LLP 2 cs (ha) | LLP 3-5 cs Nr | LLP 3-5 cs (ha) | Surface Irrigation (ha) | Groundwater Irrigation (ha) | Total Irrigation (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D | Homna | 1 Chandanpur | 0 | 0 | 21 | 121 | 0 | 0 | 100 | 12 | 8 | 3 | 8 | 0 | 0 | 5 | 61 | 0 | 0 | 77 | 134 | 210 |
| D | Homna | 2 Chalivadda | 0 | 0 | 1 | 6 | 0 | 0 | 40 | 4 | 49 | 1 | 4 | 6 | 61 | 10 | 142 | 0 | 0 | 255 | 10 | 265 |
| D | Homna | 3 Baraia Kandi | 0 | 0 | 5 | 20 | 0 | 0 | 50 | 6 | 8 | 2 | 4 | 8 | 61 | 9 | 160 | 0 | 0 | 233 | 26 | 259 |
| D | Homna | 4 Taltola | 0 | 0 | 23 | 140 | 0 | 0 | 95 | 12 | 4 | 5 | 20 | 3 | 30 | 2 | 30 | 0 | 0 | 85 | 152 | 237 |
| D | Homna | 5 Kashipur | 0 | 0 | 5 | 36 | 0 | 0 | 375 | 61 | 53 | 3 | 10 | 0 | 0 | 3 | 34 | 0 | 0 | 97 | 97 | 194 |
| D | Homna | 6 Manikarchar | 0 | 0 | 18 | 131 | 0 | 0 | 165 | 24 | 25 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 155 | 183 |
| D | Homna | 7 Homna Sadar | 0 | 0 | 42 | 227 | 0 | 0 | 200 | 20 | 4 | 0 | 0 | 0 | 0 | 14 | 93 | 0 | 0 | 97 | 247 | 344 |
| D | Homna | 8 Goari Vanga | 0 | 0 | 10 | 69 | 0 | 0 | 250 | 26 | 21 | 2 | 10 | 2 | 20 | 3 | 42 | 0 | 0 | 94 | 95 | 189 |
| D | Homna | 9 Joydebpur | 0 | 0 | 15 | 130 | 0 | 0 | 300 | 81 | 0 | 2 | 12 | 3 | 61 | 0 | 0 | 0 | 0 | 73 | 210 | 284 |
| D | Homna | 10 Bhangarchar | 0 | 0 | 7 | 101 | 0 | 0 | 20 | 4 | 10 | 2 | 8 | 2 | 61 | 0 | 0 | 0 | 0 | 79 | 105 | 184 |
| D | Homna | 11 Darichar | 0 | 0 | 34 | 113 | 0 | 0 | 575 | 63 | 9 | 3 | 12 | 0 | 0 | 8 | 130 | 0 | 0 | 151 | 176 | 327 |
| D | Homna | 12 Gangutia | 0 | 0 | 25 | 190 | 0 | 0 | 125 | 16 | 51 | 0 | 0 | 1 | 11 | 1 | 15 | 0 | 0 | 76 | 206 | 283 |
| D | Homna | 13 Dularpur | 0 | 0 | 45 | 275 | 0 | 0 | 155 | 21 | 4 | 12 | 19 | 25 | 51 | 7 | 57 | 0 | 0 | 131 | 296 | 427 |
| D | Homna | 14 Daulatpur | 0 | 0 | 4 | 24 | 0 | 0 | 400 | 81 | 61 | 0 | 0 | 4 | 49 | 5 | 81 | 0 | 0 | 190 | 105 | 295 |
| D | Homna | 15 Ram Krishnapur | 0 | 0 | 8 | 61 | 0 | 0 | 5 | 1 | 112 | 0 | 0 | 7 | 113 | 0 | 0 | 0 | 0 | 225 | 62 | 287 |
| D | Homna | 16 Chandarchar | 0 | 0 | 8 | 39 | 0 | 0 | 16 | 3 | 67 | 0 | 0 | 24 | 194 | 0 | 0 | 0 | 0 | 261 | 42 | 304 |
| D | Homna | 17 Pathalia Kandi | 0 | 0 | 8 | 58 | 0 | 0 | 120 | 22 | 53 | 2 | 10 | 0 | 0 | 10 | 162 | 0 | 0 | 225 | 80 | 305 |
| D | Homna | 18 Dhaniarchar | 0 | 0 | 25 | 73 | 0 | 0 | 137 | 20 | 2 | 5 | 10 | 0 | 0 | 12 | 182 | 0 | 0 | 194 | 93 | 287 |
| D | Homna | 19 Oparchar | 0 | 0 | 32 | 113 | 0 | 0 | 300 | 40 | 2 | 2 | 5 | 1 | 4 | 3 | 39 | 0 | 0 | 51 | 154 | 204 |
| D | Homna | 20 Mirash | 0 | 0 | 24 | 49 | 0 | 0 | 115 | 28 | 0 | 0 | 0 | 0 | 0 | 13 | 93 | 0 | 0 | 93 | 77 | 170 |
| D | Homna | 21 Nildi | 0 | 0 | 20 | 97 | 0 | 0 | 140 | 24 | 4 | 5 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 121 | 146 |
| D | Homna | 22 Monipur | 0 | 0 | 1 | 10 | 0 | 0 | 160 | 20 | 8 | 0 | 0 | 12 | 81 | 4 | 30 | 0 | 0 | 119 | 30 | 150 |
| D | Homna | 23 Anantapur | 0 | 0 | 4 | 40 | 0 | 0 | 400 | 109 | 20 | 0 | 0 | 10 | 71 | 6 | 57 | 0 | 0 | 148 | 150 | 297 |
| D | Homna | 24 Kashipur | 1 | 20 | 1 | 6 | 0 | 0 | 40 | 4 | 2 | 0 | 0 | 0 | 0 | 17 | 186 | 0 | 0 | 188 | 30 | 219 |
| D | Homna | 25 Damania | 0 | 0 | 21 | 149 | 0 | 0 | 40 | 4 | 2 | 0 | 0 | 0 | 0 | 6 | 114 | 0 | 0 | 116 | 153 | 269 |
| **Totals** | | | **1** | **20** | **407** | **2,279** | **0** | **0** | **4,323** | **708** | **580** | **50** | **156** | **108** | **867** | **138** | **1,708** | **0** | **0** | **3,312** | **3,008** | **6,319** |

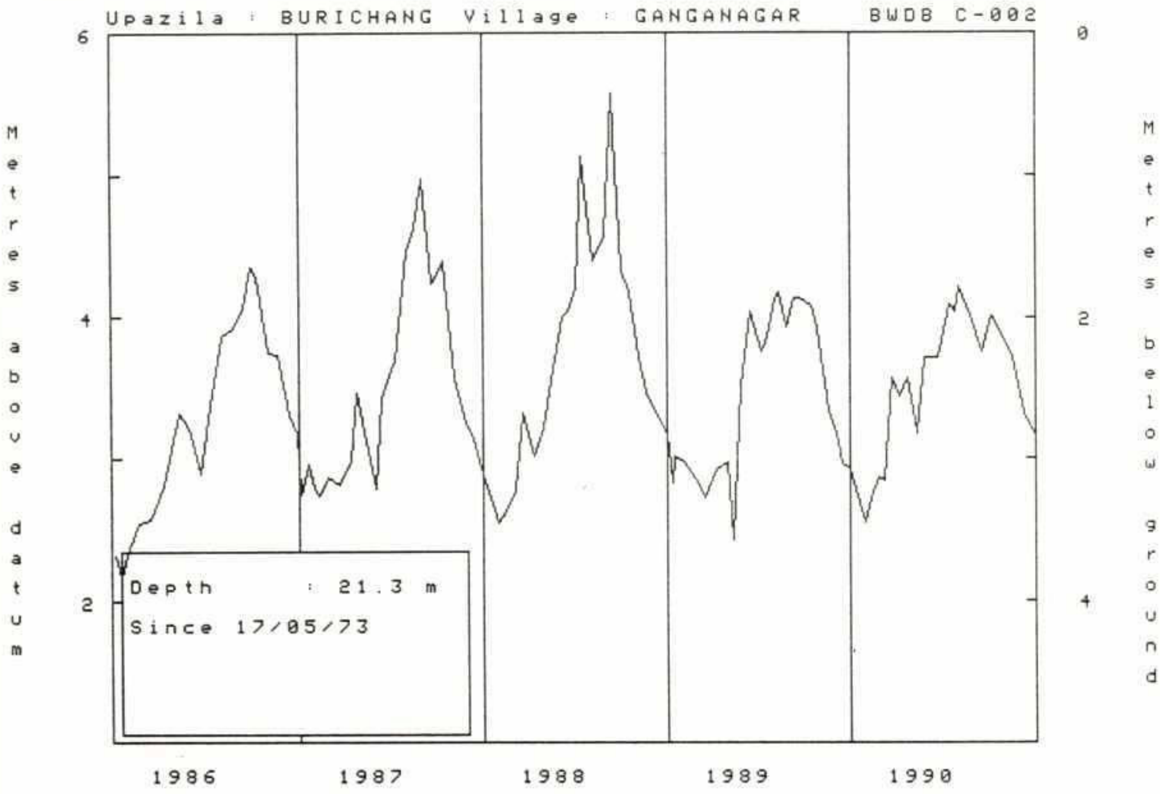
Data source : AST/CIDA (1991), DAE

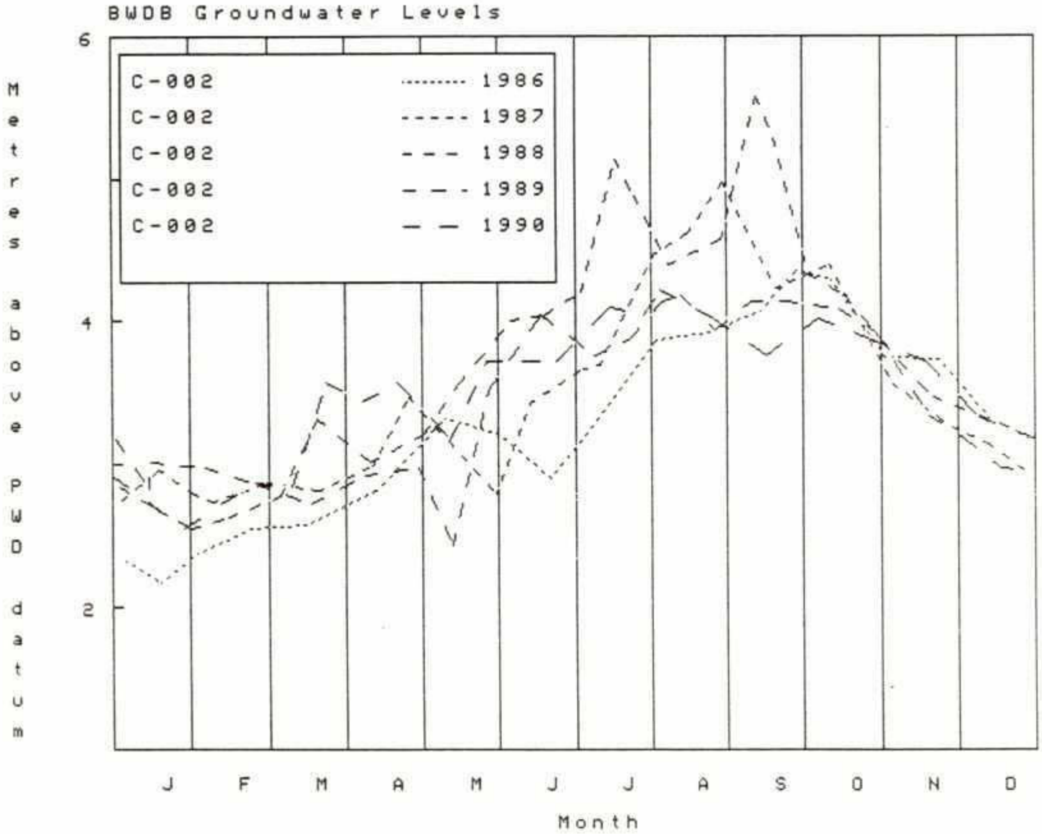
Appendix C.III

Groundwater Hydrographs

## Figure AIII.1

### Groundwater Hydrograph : Zone A, Burichang



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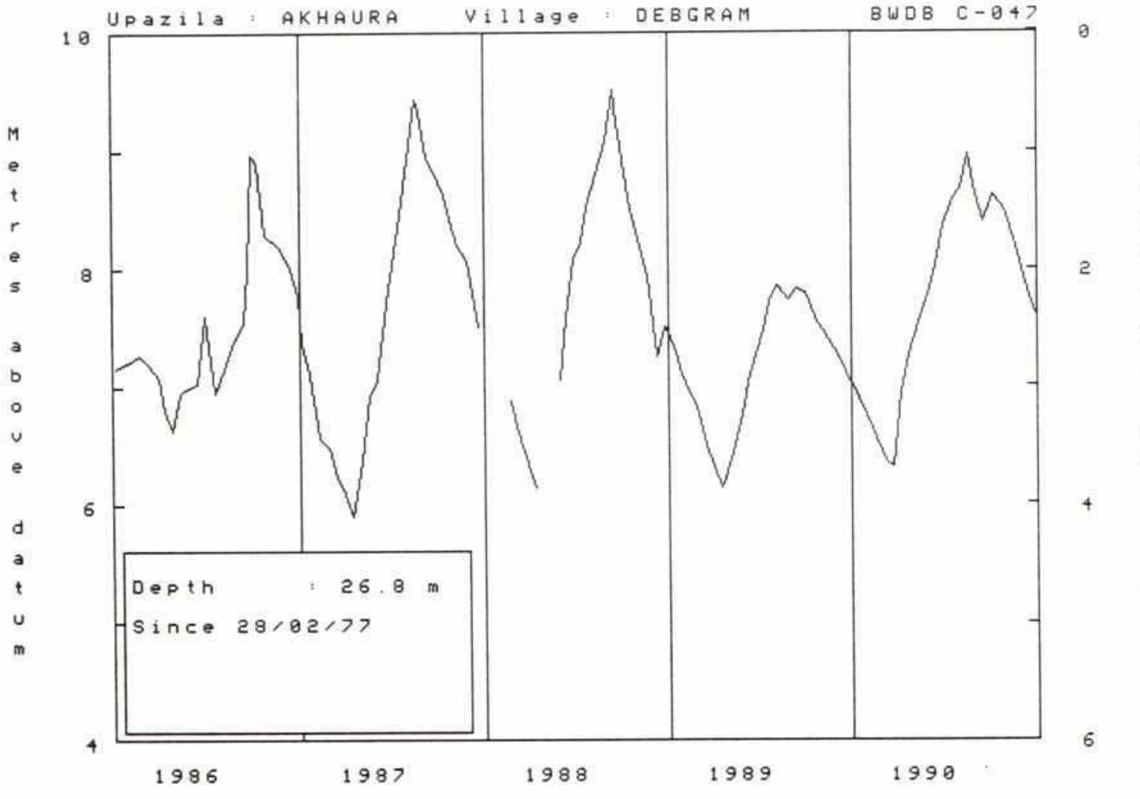
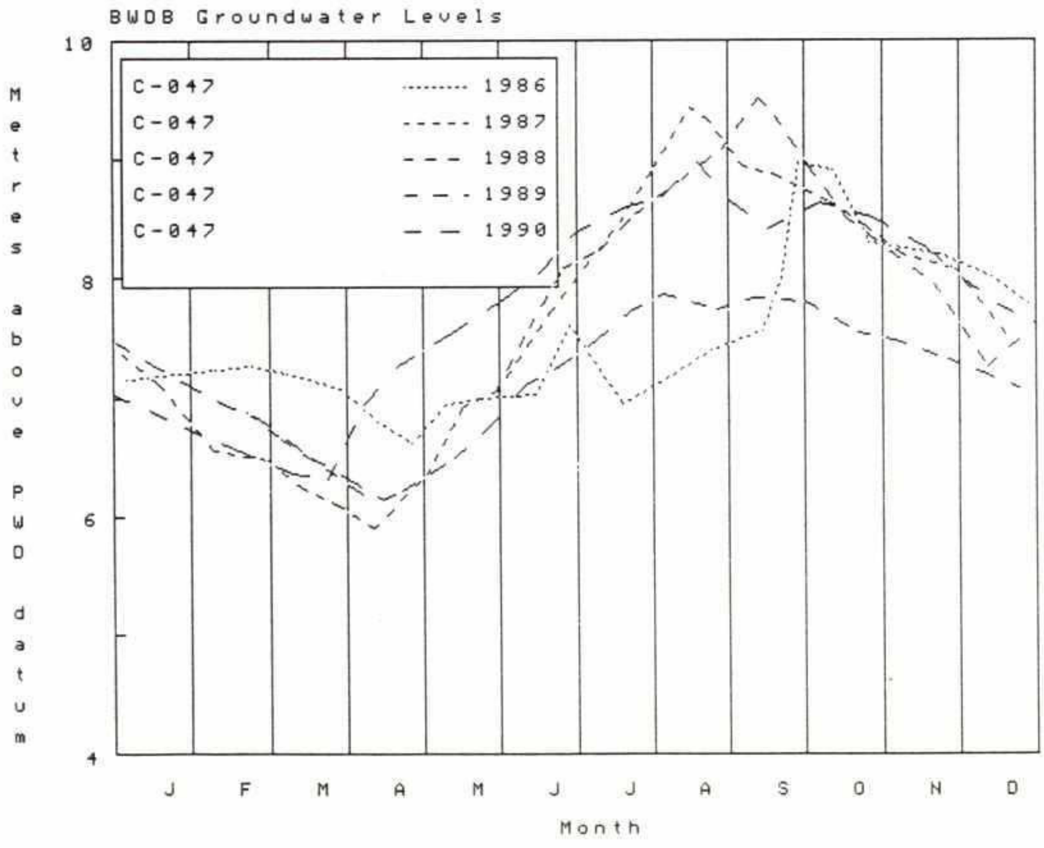
# Figure AIII.2

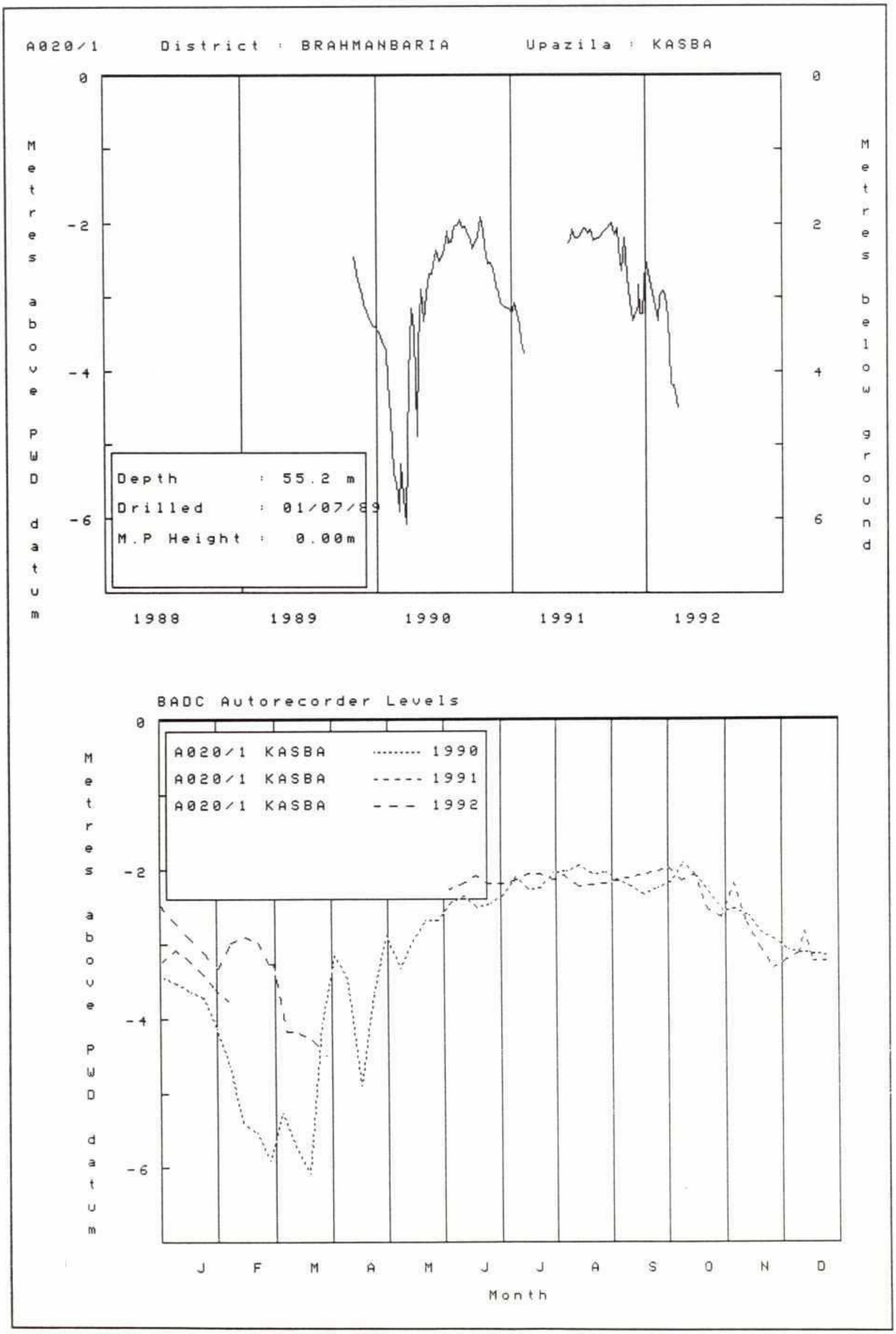
## Groundwater Hydrograph : Zone B, Akhaura



## Figure AIII.3

### Groundwater Hydrograph : Zone B, Kasba



## Figure AIII.4

### Groundwater Hydrograph : Zone C, Muradnagar

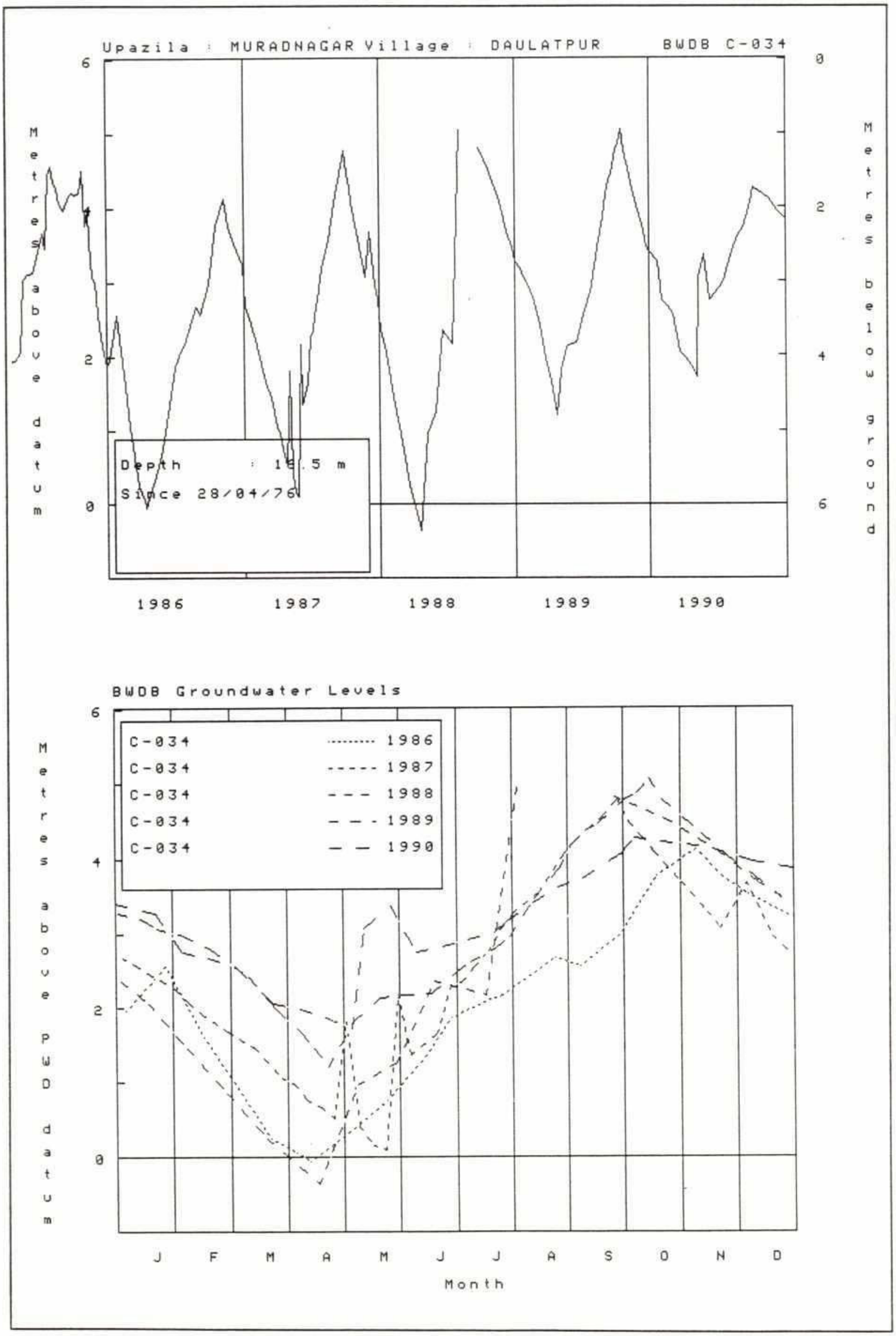
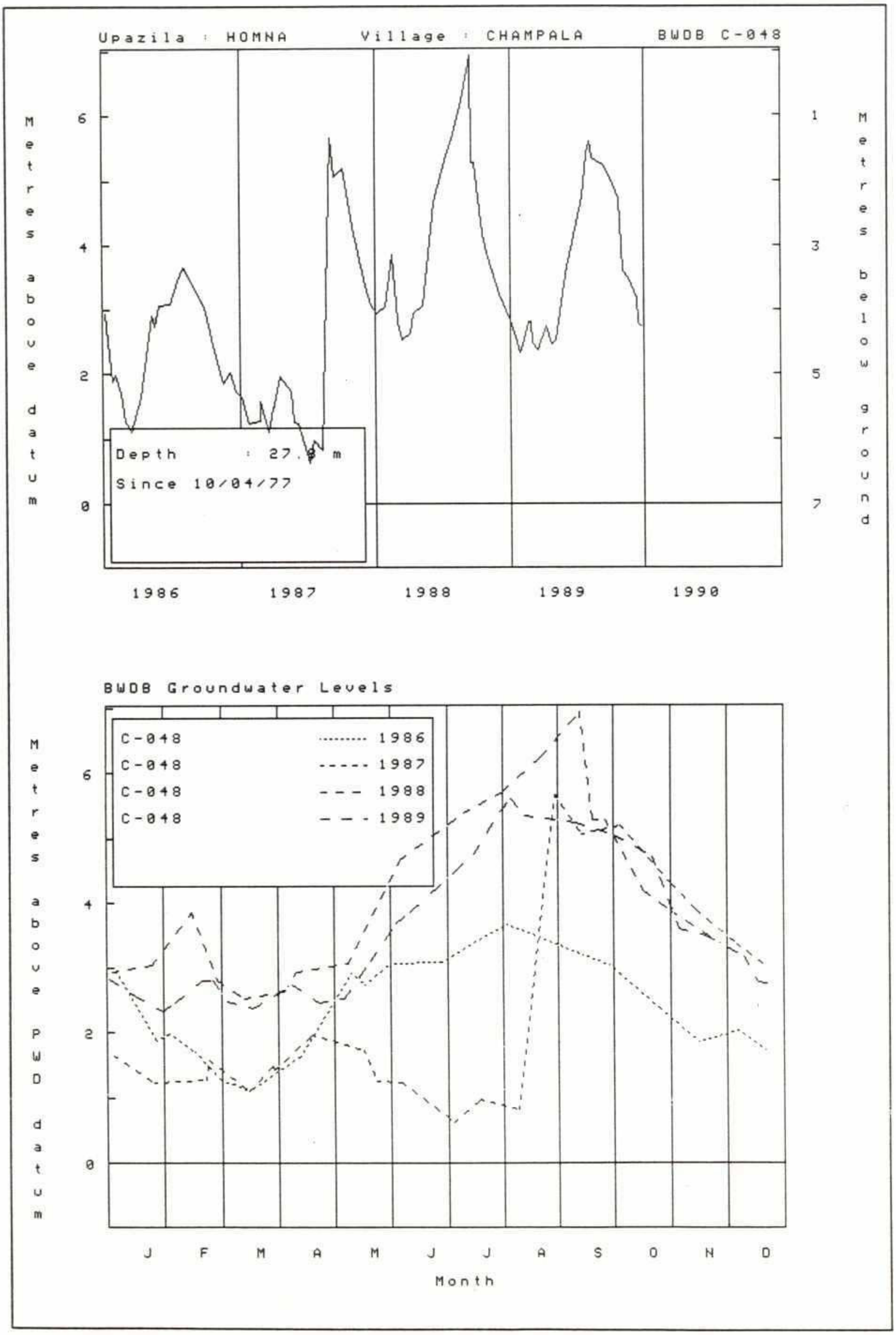


**Figure AIII.5**

**Groundwater Hydrograph : Zone D, Homna**



# APPENDIX C.IV

## Average Lithological Profiles by Thana

*Data Source : BADC / Deep Tubewell II Project*

**District : 54 - BRAHMANBARIA** **Thana : 379 - NABINAGAR**

| Depth (m) | Screen Probab- -ility | Br. % | CL % | FS % | MS % | CS % | Graphic Log | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 24 | 100 | | | | | Brown Clay | 38 | 0.020 | 0.020 |
| 2 | | 24 | 100 | | | | | | 38 | 0.020 | 0.020 |
| | | 24 | 97 | 3 | | | | | 38 | 0.022 | 0.021 |
| 4 | | 18 | 63 | 37 | | | | Grey Clay | 38 | 0.046 | 0.027 |
| | | 18 | 53 | 47 | | | | | 38 | 0.053 | 0.032 |
| 6 | | 18 | 53 | 47 | | | | | 38 | 0.053 | 0.036 |
| | | 24 | 32 | 68 | | | | Grey Fine SAND | 38 | 0.068 | 0.040 |
| 8 | | 24 | 34 | 66 | | | | | 38 | 0.066 | 0.043 |
| | | 24 | 37 | 63 | | | | | 38 | 0.064 | 0.046 |
| 10 | | 21 | 32 | 68 | | | | | 38 | 0.068 | 0.048 |
| | | 18 | 29 | 71 | | | | | 38 | 0.070 | 0.050 |
| 12 | | 18 | 26 | 74 | | | | | 38 | 0.072 | 0.052 |
| | | 24 | 24 | 76 | | | | | 38 | 0.073 | 0.053 |
| 14 | | 24 | 26 | 74 | | | | | 38 | 0.072 | 0.055 |
| | | 24 | 24 | 76 | | | | | 38 | 0.073 | 0.056 |
| 16 | | 26 | 18 | 79 | 3 | | | | 38 | 0.079 | 0.057 |
| | | 26 | 18 | 79 | 3 | | | | 38 | 0.079 | 0.059 |
| 18 | | 26 | 18 | 79 | 3 | | | | 38 | 0.079 | 0.060 |
| | | 26 | 11 | 87 | 3 | | | | 38 | 0.084 | 0.061 |
| 20 | | 26 | 11 | 87 | 3 | | | | 38 | 0.084 | 0.062 |
| | | 26 | 11 | 87 | 3 | | | | 38 | 0.084 | 0.063 |
| 22 | | 24 | 8 | 89 | 3 | | | | 38 | 0.086 | 0.064 |
| | | 24 | 8 | 89 | 3 | | | | 38 | 0.086 | 0.065 |
| 24 | | 26 | 8 | 89 | 3 | | | | 38 | 0.086 | 0.066 |
| | | 21 | 13 | 84 | 3 | | | | 38 | 0.082 | 0.067 |
| 26 | | 21 | 13 | 84 | 3 | | | | 38 | 0.082 | 0.067 |
| | | 21 | 13 | 84 | 3 | | | | 38 | 0.082 | 0.068 |
| 28 | | 24 | 13 | 82 | 5 | | | | 38 | 0.084 | 0.068 |
| | | 24 | 13 | 82 | 5 | | | | 38 | 0.084 | 0.069 |
| 30 | | 24 | 16 | 79 | 5 | | | | 38 | 0.082 | 0.069 |
| | | 24 | 8 | 79 | 13 | | | | 38 | 0.092 | 0.070 |
| 32 | | 24 | 11 | 76 | 13 | | | | 38 | 0.091 | 0.071 |
| | | 24 | 11 | 76 | 13 | | | | 38 | 0.091 | 0.071 |
| 34 | | 16 | 16 | 71 | 13 | | | | 38 | 0.087 | 0.072 |
| | | 13 | 16 | 71 | 13 | | | | 38 | 0.087 | 0.072 |
| 36 | | 13 | 18 | 68 | 13 | | | | 38 | 0.085 | 0.073 |
| | | 21 | 18 | 66 | 16 | | | | 38 | 0.087 | 0.073 |
| 38 | | 24 | 21 | 63 | 16 | | | | 38 | 0.085 | 0.073 |
| | | 29 | 16 | 63 | 21 | | | | 38 | 0.092 | 0.074 |
| 40 | | 24 | 8 | 58 | 34 | | | | 38 | 0.105 | 0.075 |
| | | 18 | 5 | 61 | 34 | | | | 38 | 0.107 | 0.075 |
| 42 | | 18 | 11 | 55 | 34 | | | | 38 | 0.103 | 0.076 |
| | | 16 | 13 | 61 | 26 | | | | 38 | 0.097 | 0.077 |
| 44 | | 16 | 13 | 61 | 26 | | | | 38 | 0.097 | 0.077 |
| | | 16 | 16 | 55 | 29 | | | | 38 | 0.096 | 0.077 |
| 46 | | 21 | 21 | 45 | 34 | | | | 38 | 0.096 | 0.078 |
| | | 24 | 21 | 39 | 39 | | | | 38 | 0.099 | 0.078 |
| 48 | | 21 | 21 | 37 | 42 | | | Grey Medium SAND | 38 | 0.101 | 0.079 |
| | | 18 | 18 | 34 | 47 | | | | 38 | 0.106 | 0.079 |
| 50 | | 18 | 18 | 34 | 47 | | | | 38 | 0.106 | 0.080 |
| | | 18 | 18 | 32 | 50 | | | | 38 | 0.107 | 0.080 |
| 52 | | 21 | 13 | 34 | 53 | | | | 38 | 0.112 | 0.081 |
| | | 21 | 13 | 34 | 53 | | | | 38 | 0.112 | 0.082 |
| 54 | | 24 | 18 | 24 | 58 | | | | 38 | 0.112 | 0.082 |
| | | 29 | 18 | 21 | 61 | | | | 38 | 0.113 | 0.083 |
| 56 | | 29 | 18 | 18 | 63 | | | | 38 | 0.115 | 0.083 |
| | | 29 | 13 | 21 | 66 | | | | 38 | 0.120 | 0.084 |
| 58 | | 34 | 11 | 18 | 71 | | | | 38 | 0.125 | 0.085 |
| | | 32 | 8 | 26 | 66 | | | | 38 | 0.124 | 0.085 |
| 60 | | 32 | 8 | 24 | 68 | | | | 38 | 0.126 | 0.086 |
| | | 29 | 5 | 24 | 71 | | | | 38 | 0.129 | 0.087 |
| 62 | | 29 | 5 | 24 | 71 | | | | 38 | 0.129 | 0.087 |
| | | 26 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.088 |
| 64 | | 26 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.089 |
| | | 26 | 11 | 13 | 76 | | | | 38 | 0.128 | 0.089 |
| 66 | | 21 | 13 | 16 | 71 | | | | 38 | 0.123 | 0.090 |
| | | 18 | 11 | 16 | 74 | | | | 38 | 0.127 | 0.090 |
| 68 | | 16 | 8 | 18 | 74 | | | | 38 | 0.129 | 0.091 |
| | | 16 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.092 |
| 70 | | 16 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.092 |
| | | 18 | 5 | 11 | 84 | | | | 38 | 0.137 | 0.093 |
| 72 | | 16 | 5 | 13 | 82 | | | | 38 | 0.135 | 0.093 |
| | | 16 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.094 |
| 74 | | 13 | 3 | 18 | 76 | 3 | | | 38 | 0.138 | 0.095 |
| | | 18 | | 21 | 76 | 3 | | | 38 | 0.140 | 0.095 |
| 76 | | 18 | | 24 | 74 | 3 | | | 38 | 0.138 | 0.096 |
| | | 16 | | 21 | 79 | | | | 38 | 0.137 | 0.096 |
| 78 | | 16 | | 19 | 81 | | | | 37 | 0.139 | 0.097 |
| | | 16 | | 19 | 81 | | | | 37 | 0.139 | 0.097 |
| 80 | | 14 | | 17 | 83 | | | | 36 | 0.140 | 0.098 |
| | | 14 | | 17 | 83 | | | | 36 | 0.140 | 0.098 |
| 82 | | 17 | | 17 | 83 | | | | 35 | 0.140 | 0.099 |
| | | 9 | 6 | 9 | 85 | | | | 34 | 0.137 | 0.099 |
| 84 | | 9 | 3 | 6 | 91 | | | | 32 | 0.142 | 0.100 |
| | | 9 | 3 | 9 | 88 | | | | 32 | 0.140 | 0.100 |

DTW Records : 38
Specific Capacity : 6.4 l/s/m

Screen Length : 33 m
Permeability : 27.2 m/d

Depth 94 m



*Data Source : BADC / Deep Tubewell II Project*

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**District : 54 - BRAHMANBARIA** **Thana : 380 - BANCHARAMPUR**

| Depth (m) | Screen Probab--ility | Br. % | CL % | FS % | MS % | CS % | Graphic Log | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 32 | 79 | 21 | | | | Brown Clay | 19 | 0.035 | 0.035 |
| 2 | | 32 | 58 | 42 | | | | | 19 | 0.049 | 0.042 |
| | | 32 | 58 | 42 | | | | | 19 | 0.049 | 0.045 |
| 4 | | 42 | 42 | 58 | | | | Brown Fine SAND | 19 | 0.061 | 0.049 |
| | | 47 | 32 | 63 | 5 | | | | 19 | 0.071 | 0.053 |
| 6 | | 47 | 32 | 63 | 5 | | | | 19 | 0.071 | 0.056 |
| | | 47 | 21 | 74 | 5 | | | | 19 | 0.078 | 0.059 |
| 8 | | 47 | 21 | 74 | 5 | | | | 19 | 0.078 | 0.062 |
| | | 47 | 21 | 74 | 5 | | | | 19 | 0.078 | 0.064 |
| 10 | | 47 | 5 | 89 | 5 | | | | 19 | 0.089 | 0.066 |
| | | 47 | 5 | 89 | 5 | | | | 19 | 0.089 | 0.068 |
| 12 | | 47 | 5 | 89 | 5 | | | | 19 | 0.089 | 0.070 |
| | | 47 | 5 | 89 | 5 | | | | 19 | 0.089 | 0.071 |
| 14 | | 47 | 5 | 95 | | | | | 19 | 0.086 | 0.073 |
| | | 47 | 5 | 95 | | | | | 19 | 0.086 | 0.073 |
| 16 | | 42 | 11 | 89 | | | | Mixed Fine SAND | 19 | 0.083 | 0.074 |
| | | 42 | 11 | 89 | | | | | 19 | 0.083 | 0.075 |
| 18 | | 42 | 11 | 89 | | | | | 19 | 0.083 | 0.075 |
| | | 37 | | 100 | | | | Grey Fine SAND | 19 | 0.090 | 0.076 |
| 20 | | 37 | | 100 | | | | | 19 | 0.090 | 0.076 |
| | | 37 | | 100 | | | | | 19 | 0.090 | 0.077 |
| 22 | | 42 | 5 | 95 | | | | Mixed Fine SAND | 19 | 0.086 | 0.078 |
| | | 37 | 5 | 95 | | | | Grey Fine SAND | 19 | 0.086 | 0.078 |
| 24 | | 37 | 5 | 95 | | | | | 19 | 0.086 | 0.078 |
| | | 37 | 5 | 79 | 16 | | | | 19 | 0.096 | 0.079 |
| 26 | | 42 | 5 | 74 | 21 | | | | 19 | 0.099 | 0.080 |
| | | 42 | 5 | 74 | 21 | | | | 19 | 0.099 | 0.080 |
| 28 | | 37 | 11 | 63 | 26 | | | | 19 | 0.098 | 0.081 |
| | | 42 | 11 | 58 | 32 | | | | 19 | 0.102 | 0.082 |
| 30 | | 37 | 11 | 47 | 42 | | | | 19 | 0.108 | 0.083 |
| | | 32 | 11 | 42 | 47 | | | Grey Medium SAND | 19 | 0.111 | 0.084 |
| 32 | | 26 | 11 | 37 | 53 | | | | 19 | 0.114 | 0.085 |
| | | 26 | 11 | 26 | 63 | | | | 19 | 0.121 | 0.086 |
| 34 | | 21 | 11 | 26 | 63 | | | | 19 | 0.121 | 0.087 |
| | | 21 | 11 | 26 | 63 | | | | 19 | 0.121 | 0.088 |
| 36 | | 21 | 11 | 26 | 63 | | | | 19 | 0.121 | 0.089 |
| | | 16 | 5 | 26 | 68 | | | | 19 | 0.127 | 0.090 |
| 38 | | 16 | 5 | 32 | 63 | | | | 19 | 0.124 | 0.091 |
| | | 16 | | 37 | 63 | | | | 19 | 0.128 | 0.091 |
| 40 | | 16 | | 37 | 63 | | | | 19 | 0.128 | 0.092 |
| | | 16 | 5 | 32 | 63 | | | | 19 | 0.124 | 0.093 |
| 42 | | 16 | 5 | 32 | 63 | | | | 19 | 0.124 | 0.094 |
| | | 21 | 5 | 32 | 63 | | | | 19 | 0.124 | 0.095 |
| 44 | | 21 | 5 | 32 | 63 | | | | 19 | 0.124 | 0.095 |
| | | 21 | 5 | 32 | 63 | | | | 19 | 0.124 | 0.096 |
| 46 | | 26 | 5 | 26 | 68 | | | | 19 | 0.127 | 0.097 |
| | | 26 | 5 | 26 | 68 | | | | 19 | 0.127 | 0.097 |
| 48 | | 26 | 5 | 16 | 79 | | | | 19 | 0.134 | 0.098 |
| | | 32 | 11 | 16 | 74 | | | | 19 | 0.127 | 0.099 |
| 50 | | 32 | 11 | 16 | 74 | | | | 19 | 0.127 | 0.099 |
| | | 37 | 11 | 21 | 68 | | | | 19 | 0.124 | 0.100 |
| 52 | | 32 | 5 | 26 | 68 | | | | 19 | 0.127 | 0.100 |
| | | 26 | 5 | 21 | 74 | | | | 19 | 0.131 | 0.101 |
| 54 | | 21 | 5 | 16 | 79 | | | | 19 | 0.134 | 0.101 |
| | | 32 | 5 | 21 | 74 | | | | 19 | 0.131 | 0.102 |
| 56 | | 32 | 5 | 21 | 74 | | | | 19 | 0.131 | 0.102 |
| | | 47 | 5 | 47 | 47 | | | Mixed Fine SAND | 19 | 0.115 | 0.103 |
| 58 | | 47 | | 47 | 53 | | | Mixed Medium SAND | 19 | 0.122 | 0.103 |
| | | 42 | | 47 | 53 | | | Grey Medium SAND | 19 | 0.122 | 0.103 |
| 60 | | 42 | | 47 | 53 | | | | 19 | 0.122 | 0.104 |
| | | 47 | | 42 | 58 | | | | 19 | 0.125 | 0.104 |
| 62 | | 47 | | 42 | 58 | | | | 19 | 0.125 | 0.104 |
| | | 47 | | 37 | 63 | | | | 19 | 0.128 | 0.105 |
| 64 | | 47 | | 32 | 63 | 5 | | | 19 | 0.136 | 0.105 |
| | | 42 | | 21 | 74 | 5 | | | 19 | 0.143 | 0.106 |
| 66 | | 42 | | 21 | 68 | 11 | | | 19 | 0.148 | 0.106 |
| | | 32 | 5 | 16 | 68 | 11 | | | 19 | 0.144 | 0.107 |
| 68 | | 32 | 5 | 16 | 68 | 11 | | | 19 | 0.144 | 0.107 |
| | | 32 | 5 | 11 | 74 | 11 | | | 19 | 0.147 | 0.108 |
| 70 | | 32 | 5 | 11 | 74 | 11 | | | 19 | 0.147 | 0.109 |
| | | 26 | 5 | 5 | 79 | 11 | | | 19 | 0.151 | 0.109 |
| 72 | | 26 | 5 | 5 | 79 | 11 | | | 19 | 0.151 | 0.110 |
| | | 26 | 5 | 5 | 79 | 11 | | | 19 | 0.151 | 0.110 |
| 74 | | 26 | 5 | 5 | 79 | 11 | | | 19 | 0.151 | 0.111 |
| | | 37 | 5 | 16 | 68 | 11 | | | 19 | 0.144 | 0.111 |
| 76 | | 37 | 5 | 16 | 68 | 11 | | | 19 | 0.144 | 0.112 |
| | | 37 | 5 | 16 | 74 | 5 | | | 19 | 0.139 | 0.112 |
| 78 | | 42 | 5 | 26 | 63 | 5 | | | 19 | 0.133 | 0.112 |
| | | 42 | | 32 | 63 | 5 | | | 19 | 0.136 | 0.113 |
| 80 | | 42 | | 32 | 63 | 5 | | | 19 | 0.136 | 0.113 |
| | | 42 | | 37 | 58 | 5 | | | 19 | 0.133 | 0.113 |
| 82 | | 42 | | 37 | 58 | 5 | | | 19 | 0.133 | 0.113 |
| | | 47 | | 47 | 47 | 6 | | Mixed Fine SAND | 17 | 0.128 | 0.114 |
| 84 | | 47 | | 47 | 47 | 7 | | | 15 | 0.129 | 0.114 |
| | | 47 | | 47 | 47 | 7 | | | 15 | 0.129 | 0.114 |

DTW Records : 19
Specific Capacity : 5.6 l/s/m

Screen Length : 37 m
Permeability : 21.2 m/d

Depth 86 m

*Data Source : BADC / Deep Tubewell II Project*

District : 54 - BRAHMANBARIA

Thana : 378 - KASBA

| Depth (m) | Screen Probab- -ility | Br. % | CL % | FS % | MS % | CS % | Graphic Log | Lithology | Nr of Records | Layer Specific Yield m/d | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 36 | 100 | | | | | Brown Clay | 25 | 0.020 | 0.020 |
| 2 | | 36 | 96 | 4 | | | | | 25 | 0.023 | 0.021 |
| | | 36 | 96 | 4 | | | | | 25 | 0.023 | 0.022 |
| 4 | | 20 | 76 | 24 | | | | Grey Clay | 25 | 0.037 | 0.026 |
| | | 20 | 76 | 24 | | | | | 25 | 0.037 | 0.028 |
| 6 | | 16 | 72 | 28 | | | | | 25 | 0.040 | 0.030 |
| | | 12 | 68 | 32 | | | | | 25 | 0.042 | 0.032 |
| 8 | | 12 | 68 | 32 | | | | | 25 | 0.042 | 0.033 |
| | | 12 | 64 | 36 | | | | | 25 | 0.045 | 0.034 |
| 10 | | 12 | 64 | 36 | | | | | 25 | 0.045 | 0.035 |
| | | 16 | 64 | 36 | | | | | 25 | 0.045 | 0.036 |
| 12 | | 16 | 52 | 48 | | | | | 25 | 0.054 | 0.038 |
| | | 16 | 52 | 48 | | | | | 25 | 0.054 | 0.039 |
| 14 | | 20 | 48 | 52 | | | | Grey Fine SAND | 25 | 0.056 | 0.040 |
| | | 20 | 44 | 56 | | | | | 25 | 0.059 | 0.041 |
| 16 | | 20 | 40 | 60 | | | | | 25 | 0.062 | 0.043 |
| | | 16 | 32 | 64 | | 4 | | | 25 | 0.074 | 0.045 |
| 18 | | 16 | 36 | 56 | 4 | 4 | | | 25 | 0.074 | 0.046 |
| | | 20 | 36 | 52 | 8 | 4 | | | 25 | 0.076 | 0.048 |
| 20 | | 20 | 28 | 60 | 12 | | | | 25 | 0.078 | 0.049 |
| | | 20 | 20 | 68 | 12 | | | | 25 | 0.083 | 0.051 |
| 22 | | 24 | 24 | 60 | 16 | | | | 25 | 0.083 | 0.052 |
| | | 28 | 36 | 44 | 20 | | | | 25 | 0.077 | 0.053 |
| 24 | | 32 | 40 | 44 | 16 | | | | 25 | 0.072 | 0.054 |
| | | 36 | 48 | 36 | 12 | 4 | | Grey Clay | 25 | 0.070 | 0.055 |
| 26 | | 32 | 44 | 36 | 12 | 8 | | | 25 | 0.079 | 0.056 |
| | | 32 | 52 | 32 | 8 | 8 | | | 25 | 0.071 | 0.056 |
| 28 | | 36 | 52 | 28 | 16 | 4 | | | 25 | 0.070 | 0.057 |
| | | 36 | 52 | 12 | 32 | 4 | | | 25 | 0.079 | 0.058 |
| 30 | | 36 | 52 | 12 | 36 | | | | 25 | 0.075 | 0.058 |
| | | 36 | 52 | 16 | 32 | | | | 25 | 0.073 | 0.059 |
| 32 | | 32 | 44 | 20 | 36 | | | | 25 | 0.081 | 0.059 |
| | | 32 | 40 | 24 | 36 | | | | 25 | 0.084 | 0.060 |
| 34 | | 28 | 36 | 20 | 44 | | | Grey Medium SAND | 25 | 0.091 | 0.061 |
| | | 32 | 32 | 28 | 40 | | | | 25 | 0.092 | 0.062 |
| 36 | | 32 | 20 | 36 | 44 | | | | 25 | 0.102 | 0.063 |
| | | 32 | 16 | 44 | 40 | | | Grey Fine SAND | 25 | 0.103 | 0.064 |
| 38 | | 40 | 20 | 44 | 36 | | | | 25 | 0.098 | 0.065 |
| | | 40 | 24 | 36 | 40 | | | Grey Medium SAND | 25 | 0.097 | 0.066 |
| 40 | | 36 | 20 | 40 | 40 | | | Grey Fine SAND | 25 | 0.100 | 0.067 |
| | | 32 | 24 | 36 | 40 | | | Grey Medium SAND | 25 | 0.097 | 0.067 |
| 42 | | 36 | 24 | 36 | 40 | | | | 25 | 0.097 | 0.068 |
| | | 36 | 16 | 36 | 48 | | | | 25 | 0.108 | 0.069 |
| 44 | | 24 | 12 | 24 | 64 | | | | 25 | 0.120 | 0.070 |
| | | 28 | 20 | 24 | 56 | | | | 25 | 0.110 | 0.071 |
| 46 | | 28 | 24 | 24 | 52 | | | | 25 | 0.104 | 0.072 |
| | | 32 | 12 | 36 | 52 | | | | 25 | 0.113 | 0.073 |
| 48 | | 32 | 12 | 36 | 52 | | | | 25 | 0.113 | 0.073 |
| | | 40 | 12 | 40 | 48 | | | | 25 | 0.110 | 0.074 |
| 50 | | 40 | 12 | 32 | 56 | | | | 25 | 0.115 | 0.075 |
| | | 40 | 12 | 32 | 56 | | | | 25 | 0.115 | 0.076 |
| 52 | | 36 | 12 | 20 | 68 | | | | 25 | 0.122 | 0.077 |
| | | 36 | 12 | 16 | 72 | | | | 25 | 0.125 | 0.078 |
| 54 | | 32 | 12 | 16 | 72 | | | | 25 | 0.125 | 0.078 |
| | | 28 | 12 | 12 | 76 | | | | 25 | 0.127 | 0.079 |
| 56 | | 28 | 12 | 8 | 76 | 4 | | | 25 | 0.134 | 0.080 |
| | | 28 | 12 | 8 | 76 | 4 | | | 25 | 0.134 | 0.081 |
| 58 | | 24 | 8 | 8 | 76 | 8 | | | 25 | 0.143 | 0.082 |
| | | 20 | 4 | 12 | 76 | 8 | | | 25 | 0.146 | 0.083 |
| 60 | | 20 | 4 | 16 | 72 | 8 | | | 25 | 0.143 | 0.084 |
| | | 12 | 4 | 12 | 76 | 8 | | | 25 | 0.146 | 0.085 |
| 62 | | 12 | 8 | 20 | 68 | | | | 25 | 0.134 | 0.086 |
| | | 12 | 8 | 24 | 64 | | | | 25 | 0.131 | 0.087 |
| 64 | | 12 | 8 | 20 | 68 | | | | 25 | 0.134 | 0.088 |
| | | 12 | 8 | 24 | 64 | 4 | | | 25 | 0.129 | 0.088 |
| 66 | | 12 | 8 | 20 | 68 | 4 | | | 25 | 0.132 | 0.089 |
| | | 16 | 4 | 20 | 64 | 12 | | | 25 | 0.145 | 0.090 |
| 68 | | 16 | 4 | 24 | 60 | 12 | | | 25 | 0.142 | 0.091 |
| | | 12 | 4 | 24 | 60 | 12 | | | 25 | 0.142 | 0.091 |
| 70 | | 12 | | 28 | 64 | 8 | | | 25 | 0.141 | 0.092 |
| | | 16 | 4 | 24 | 64 | 8 | | | 25 | 0.138 | 0.093 |
| 72 | | 16 | 4 | 28 | 60 | 8 | | | 25 | 0.136 | 0.093 |
| | | 16 | 4 | 28 | 56 | 12 | | | 25 | 0.140 | 0.094 |
| 74 | | 16 | 8 | 28 | 52 | 12 | | | 25 | 0.135 | 0.094 |
| | | 12 | 8 | 12 | 68 | 12 | | | 25 | 0.144 | 0.095 |
| 76 | | 12 | 8 | 12 | 68 | 12 | | | 25 | 0.144 | 0.096 |
| | | 12 | 4 | 12 | 72 | 12 | | | 25 | 0.150 | 0.096 |
| 78 | | 12 | 4 | 8 | 68 | 16 | | | 25 | 0.162 | 0.097 |
| | | 8 | 4 | 4 | 68 | 20 | | | 25 | 0.168 | 0.098 |
| 80 | | 4 | | 4 | 76 | 12 | | | 25 | 0.172 | 0.099 |
| | | | | 8 | 68 | 16 | | | 25 | 0.173 | 0.100 |
| 82 | | | 4 | 4 | 64 | 20 | | | 25 | 0.174 | 0.101 |
| | | 4 | 4 | 4 | 64 | 20 | | | 25 | 0.174 | 0.102 |
| 84 | | 4 | 4 | 12 | 68 | 16 | | | 25 | 0.154 | 0.102 |
| | | 4 | 4 | 13 | 71 | 13 | | | 24 | 0.150 | 0.103 |

DTW Records : 25
Specific Capacity : 6.3 l/s/m

Screen Length : 36 m
Permeability : 24.6 m/d

Depth 97 m

*Data Source : BADC ' Deep Tubewell II Project*

District : **54 - BRAHMANBARIA** Thana : 379 - **NABINAGAR**

| Depth (m) | Screen Probab--ility | Br. % | CL % | FS % | MS % | CS % | Graphic Log | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 24 | 100 | | | | | Brown Clay | 38 | 0.020 | 0.020 |
| 2 | | 24 | 100 | | | | | | 38 | 0.020 | 0.020 |
| | | 24 | 97 | 3 | | | | | 38 | 0.022 | 0.021 |
| 4 | | 18 | 63 | 37 | | | | Grey Clay | 38 | 0.046 | 0.027 |
| | | 18 | 53 | 47 | | | | | 38 | 0.053 | 0.032 |
| 6 | | 18 | 53 | 47 | | | | | 38 | 0.053 | 0.036 |
| | | 24 | 32 | 68 | | | | Grey Fine SAND | 38 | 0.068 | 0.040 |
| 8 | | 24 | 34 | 66 | | | | | 38 | 0.066 | 0.043 |
| | | 24 | 37 | 63 | | | | | 38 | 0.064 | 0.046 |
| 10 | | 21 | 32 | 68 | | | | | 38 | 0.068 | 0.048 |
| | | 18 | 29 | 71 | | | | | 38 | 0.070 | 0.050 |
| 12 | | 18 | 26 | 74 | | | | | 38 | 0.072 | 0.052 |
| | | 24 | 24 | 76 | | | | | 38 | 0.073 | 0.053 |
| 14 | | 24 | 26 | 74 | | | | | 38 | 0.072 | 0.055 |
| | | 24 | 24 | 76 | | | | | 38 | 0.073 | 0.056 |
| 16 | | 26 | 18 | 79 | 3 | | | | 38 | 0.079 | 0.057 |
| | | 26 | 18 | 79 | 3 | | | | 38 | 0.079 | 0.059 |
| 18 | | 26 | 18 | 79 | 3 | | | | 38 | 0.079 | 0.060 |
| | | 26 | 11 | 87 | 3 | | | | 38 | 0.084 | 0.061 |
| 20 | | 26 | 11 | 87 | 3 | | | | 38 | 0.084 | 0.062 |
| | | 26 | 11 | 87 | 3 | | | | 38 | 0.084 | 0.063 |
| 22 | | 24 | 8 | 89 | 3 | | | | 38 | 0.086 | 0.064 |
| | | 24 | 8 | 89 | 3 | | | | 38 | 0.086 | 0.065 |
| 24 | | 26 | 8 | 89 | 3 | | | | 38 | 0.086 | 0.066 |
| | | 21 | 13 | 84 | 3 | | | | 38 | 0.082 | 0.067 |
| 26 | | 21 | 13 | 84 | 3 | | | | 38 | 0.082 | 0.067 |
| | | 21 | 13 | 84 | 3 | | | | 38 | 0.082 | 0.068 |
| 28 | | 24 | 13 | 82 | 5 | | | | 38 | 0.084 | 0.068 |
| | | 24 | 13 | 82 | 5 | | | | 38 | 0.084 | 0.069 |
| 30 | | 24 | 16 | 79 | 5 | | | | 38 | 0.082 | 0.069 |
| | | 24 | 8 | 79 | 13 | | | | 38 | 0.092 | 0.070 |
| 32 | | 24 | 11 | 76 | 13 | | | | 38 | 0.091 | 0.071 |
| | | 24 | 11 | 76 | 13 | | | | 38 | 0.091 | 0.071 |
| 34 | | 16 | 16 | 71 | 13 | | | | 38 | 0.087 | 0.072 |
| | | 13 | 16 | 71 | 13 | | | | 38 | 0.087 | 0.072 |
| 36 | | 13 | 18 | 68 | 13 | | | | 38 | 0.085 | 0.073 |
| | | 21 | 18 | 66 | 16 | | | | 38 | 0.087 | 0.073 |
| 38 | | 24 | 21 | 63 | 16 | | | | 38 | 0.085 | 0.073 |
| | | 29 | 16 | 63 | 21 | | | | 38 | 0.092 | 0.074 |
| 40 | | 24 | 8 | 58 | 34 | | | | 38 | 0.105 | 0.075 |
| | | 18 | 5 | 61 | 34 | | | | 38 | 0.107 | 0.075 |
| 42 | | 18 | 11 | 55 | 34 | | | | 38 | 0.103 | 0.076 |
| | | 16 | 13 | 61 | 26 | | | | 38 | 0.097 | 0.077 |
| 44 | | 16 | 13 | 61 | 26 | | | | 38 | 0.097 | 0.077 |
| | | 16 | 16 | 55 | 29 | | | | 38 | 0.096 | 0.077 |
| 46 | | 21 | 21 | 45 | 34 | | | | 38 | 0.096 | 0.078 |
| | | 24 | 21 | 39 | 39 | | | | 38 | 0.099 | 0.078 |
| 48 | | 21 | 21 | 37 | 42 | | | Grey Medium SAND | 38 | 0.101 | 0.079 |
| | | 18 | 18 | 34 | 47 | | | | 38 | 0.106 | 0.079 |
| 50 | | 18 | 18 | 34 | 47 | | | | 38 | 0.106 | 0.080 |
| | | 18 | 18 | 32 | 50 | | | | 38 | 0.107 | 0.080 |
| 52 | | 21 | 13 | 34 | 53 | | | | 38 | 0.112 | 0.081 |
| | | 21 | 13 | 34 | 53 | | | | 38 | 0.112 | 0.082 |
| 54 | | 24 | 18 | 24 | 58 | | | | 38 | 0.112 | 0.082 |
| | | 29 | 18 | 21 | 61 | | | | 38 | 0.113 | 0.083 |
| 56 | | 29 | 18 | 18 | 63 | | | | 38 | 0.115 | 0.083 |
| | | 29 | 13 | 21 | 66 | | | | 38 | 0.120 | 0.084 |
| 58 | | 34 | 11 | 18 | 71 | | | | 38 | 0.125 | 0.085 |
| | | 32 | 8 | 26 | 66 | | | | 38 | 0.124 | 0.085 |
| 60 | | 32 | 8 | 24 | 68 | | | | 38 | 0.126 | 0.086 |
| | | 29 | 5 | 24 | 71 | | | | 38 | 0.129 | 0.087 |
| 62 | | 29 | 5 | 24 | 71 | | | | 38 | 0.129 | 0.087 |
| | | 26 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.088 |
| 64 | | 26 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.089 |
| | | 26 | 11 | 13 | 76 | | | | 38 | 0.128 | 0.089 |
| 66 | | 21 | 13 | 16 | 71 | | | | 38 | 0.123 | 0.090 |
| | | 18 | 11 | 16 | 74 | | | | 38 | 0.127 | 0.090 |
| 68 | | 16 | 8 | 18 | 74 | | | | 38 | 0.129 | 0.091 |
| | | 16 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.092 |
| 70 | | 16 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.092 |
| | | 18 | 5 | 11 | 84 | | | | 38 | 0.137 | 0.093 |
| 72 | | 16 | 5 | 13 | 82 | | | | 38 | 0.135 | 0.093 |
| | | 16 | 5 | 16 | 79 | | | | 38 | 0.134 | 0.094 |
| 74 | | 13 | 3 | 18 | 76 | 3 | | | 38 | 0.138 | 0.095 |
| | | 18 | | 21 | 76 | 3 | | | 38 | 0.140 | 0.095 |
| 76 | | 18 | | 24 | 74 | 3 | | | 38 | 0.138 | 0.096 |
| | | 16 | | 21 | 79 | | | | 38 | 0.137 | 0.096 |
| 78 | | 15 | | 19 | 81 | | | | 37 | 0.139 | 0.097 |
| | | 16 | | 19 | 81 | | | | 37 | 0.139 | 0.097 |
| 80 | | 14 | | 17 | 83 | | | | 36 | 0.140 | 0.098 |
| | | 14 | | 17 | 83 | | | | 36 | 0.140 | 0.098 |
| 82 | | 17 | | 17 | 83 | | | | 35 | 0.140 | 0.099 |
| | | 9 | 6 | 9 | 85 | | | | 34 | 0.137 | 0.099 |
| 84 | | 9 | 3 | 6 | 91 | | | | 32 | 0.142 | 0.100 |
| | | 9 | 3 | 9 | 88 | | | | 32 | 0.140 | 0.100 |

DTW Records : 38
Specific Capacity : 6.4 l/s/m

Screen Length : 33 m
Permeability : 27.2 m/d

Depth 94 m

*Data Source : BADC / Deep Tubewell II Project*

District : 55 - COMILLA

Thana : 385 - BRAHMANPARA

| Depth (m) | Br. % | CL % | FS % | MS % | CS % | Lithology | Nr of Records | Layer Specific Yield m/d | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|
| | 12 | 98 | 2 | | | Grey Clay | 52 | 0.021 | 0.021 |
| 2 | 12 | 98 | 2 | | | | 52 | 0.021 | 0.021 |
| | 13 | 96 | 4 | | | | 52 | 0.023 | 0.022 |
| 4 | 25 | 77 | 21 | | | Mixed Clay | 52 | 0.035 | 0.025 |
| | 25 | 77 | 21 | | | | 52 | 0.035 | 0.027 |
| 6 | 27 | 75 | 23 | | | Brown Clay | 52 | 0.037 | 0.029 |
| | 38 | 62 | 35 | 4 | | | 52 | 0.049 | 0.032 |
| 8 | 40 | 58 | 38 | 4 | | | 52 | 0.052 | 0.034 |
| | 40 | 58 | 38 | 4 | | | 52 | 0.052 | 0.036 |
| 10 | 38 | 58 | 38 | 4 | | | 52 | 0.052 | 0.038 |
| | 38 | 58 | 38 | 4 | | | 52 | 0.052 | 0.039 |
| 12 | 38 | 58 | 38 | 4 | | | 52 | 0.052 | 0.040 |
| | 35 | 50 | 44 | 6 | | Grey Clay | 52 | 0.058 | 0.042 |
| 14 | 37 | 48 | 44 | 8 | | | 52 | 0.061 | 0.043 |
| | 38 | 46 | 46 | 8 | | | 52 | 0.062 | 0.044 |
| 16 | 37 | 38 | 54 | 8 | | Grey Fine SAND | 52 | 0.068 | 0.046 |
| | 38 | 37 | 56 | 8 | | | 52 | 0.069 | 0.047 |
| 18 | 38 | 38 | 56 | 6 | | | 52 | 0.067 | 0.048 |
| | 37 | 31 | 62 | 8 | | | 52 | 0.073 | 0.049 |
| 20 | 38 | 25 | 67 | 8 | | | 52 | 0.077 | 0.051 |
| | 38 | 25 | 67 | 8 | | | 52 | 0.077 | 0.052 |
| 22 | 38 | 17 | 75 | 8 | | | 52 | 0.083 | 0.053 |
| | 37 | 17 | 75 | 8 | | | 52 | 0.083 | 0.055 |
| 24 | 37 | 17 | 73 | 10 | | | 52 | 0.084 | 0.056 |
| | 37 | 12 | 71 | 15 | | | 52 | 0.090 | 0.057 |
| 26 | 38 | 10 | 69 | 17 | | | 52 | 0.092 | 0.059 |
| | 40 | 4 | 71 | 21 | | | 52 | 0.098 | 0.060 |
| 28 | 40 | 4 | 71 | 21 | | | 52 | 0.098 | 0.062 |
| | 42 | 4 | 67 | 25 | | | 52 | 0.101 | 0.063 |
| 30 | 42 | 2 | 65 | 29 | | | 52 | 0.104 | 0.064 |
| | 42 | 2 | 63 | 31 | | | 52 | 0.106 | 0.066 |
| 32 | 42 | 4 | 62 | 31 | | | 52 | 0.104 | 0.067 |
| | 44 | 4 | 58 | 33 | 2 | | 52 | 0.108 | 0.068 |
| 34 | 44 | 4 | 58 | 33 | 2 | | 52 | 0.108 | 0.069 |
| | 44 | 4 | 56 | 35 | 2 | | 52 | 0.110 | 0.070 |
| 36 | 44 | 4 | 50 | 40 | 2 | | 52 | 0.113 | 0.072 |
| | 44 | 4 | 50 | 42 | 2 | | 52 | 0.115 | 0.073 |
| 38 | 42 | 4 | 50 | 42 | 2 | | 52 | 0.115 | 0.074 |
| | 46 | 4 | 48 | 44 | 2 | | 52 | 0.116 | 0.075 |
| 40 | 50 | 4 | 46 | 46 | 2 | Brown Fine SAND | 52 | 0.117 | 0.076 |
| | 50 | 4 | 44 | 48 | 2 | Brown Medium SAND | 52 | 0.118 | 0.077 |
| 42 | 50 | 4 | 44 | 48 | 2 | Mixed Medium SAND | 52 | 0.118 | 0.078 |
| | 50 | 4 | 42 | 50 | 2 | | 52 | 0.120 | 0.079 |
| 44 | 48 | 6 | 38 | 52 | 2 | Grey Medium SAND | 52 | 0.119 | 0.080 |
| | 48 | 6 | 37 | 54 | 2 | | 52 | 0.121 | 0.081 |
| 46 | 48 | 6 | 37 | 54 | 2 | | 52 | 0.121 | 0.082 |
| | 46 | 4 | 38 | 54 | 2 | | 52 | 0.122 | 0.083 |
| 48 | 42 | 8 | 35 | 54 | 2 | | 52 | 0.119 | 0.083 |
| | 35 | 8 | 31 | 60 | | | 52 | 0.120 | 0.084 |
| 50 | 35 | 6 | 29 | 63 | | | 52 | 0.123 | 0.085 |
| | 35 | 6 | 31 | 63 | | | 52 | 0.124 | 0.086 |
| 52 | 35 | 6 | 27 | 67 | | | 52 | 0.126 | 0.086 |
| | 35 | 6 | 25 | 69 | | | 52 | 0.128 | 0.087 |
| 54 | 29 | 8 | 21 | 71 | | | 52 | 0.127 | 0.088 |
| | 33 | 10 | 23 | 67 | | | 52 | 0.124 | 0.089 |
| 56 | 33 | 10 | 25 | 65 | | | 52 | 0.123 | 0.089 |
| | 31 | 12 | 27 | 62 | | | 52 | 0.119 | 0.090 |
| 58 | 29 | 13 | 27 | 60 | | | 52 | 0.116 | 0.090 |
| | 27 | 15 | 23 | 62 | | | 52 | 0.116 | 0.091 |
| 60 | 27 | 17 | 23 | 60 | | | 52 | 0.114 | 0.091 |
| | 27 | 15 | 19 | 65 | | | 52 | 0.118 | 0.091 |
| 62 | 21 | 19 | 15 | 65 | | | 52 | 0.116 | 0.092 |
| | 21 | 19 | 19 | 62 | | | 52 | 0.113 | 0.092 |
| 64 | 19 | 19 | 17 | 63 | | | 52 | 0.115 | 0.093 |
| | 15 | 23 | 17 | 60 | | | 52 | 0.110 | 0.093 |
| 66 | 19 | 17 | 15 | 67 | | | 52 | 0.118 | 0.093 |
| | 19 | 15 | 15 | 69 | | | 52 | 0.121 | 0.094 |
| 68 | 17 | 10 | 13 | 77 | | | 52 | 0.129 | 0.094 |
| | 15 | 12 | 10 | 79 | | | 52 | 0.129 | 0.095 |
| 70 | 15 | 10 | 6 | 85 | | | 52 | 0.134 | 0.095 |
| | 18 | 10 | 10 | 80 | | | 51 | 0.131 | 0.096 |
| 72 | 18 | 12 | 6 | 82 | | | 51 | 0.131 | 0.096 |
| | 18 | 14 | 6 | 80 | | | 51 | 0.129 | 0.097 |
| 74 | 14 | 12 | 6 | 82 | | | 50 | 0.131 | 0.097 |
| | 16 | 14 | 6 | 80 | | | 50 | 0.128 | 0.097 |
| 76 | 16 | 14 | 6 | 80 | | | 50 | 0.128 | 0.098 |
| | 17 | 15 | 8 | 77 | | | 48 | 0.126 | 0.098 |
| 78 | 15 | 13 | 4 | 83 | | | 47 | 0.131 | 0.099 |
| | 15 | 13 | 4 | 83 | | | 47 | 0.131 | 0.099 |
| 80 | 9 | 11 | 5 | 82 | | | 44 | 0.130 | 0.099 |
| | 9 | 18 | 5 | 75 | | | 44 | 0.121 | 0.100 |
| 82 | 9 | 20 | 5 | 73 | | | 44 | 0.118 | 0.100 |
| | 9 | 28 | 5 | 65 | | | 43 | 0.109 | 0.100 |
| 84 | 9 | 30 | 7 | 60 | | | 43 | 0.104 | 0.100 |
| | 9 | 30 | 7 | 60 | | | 43 | 0.104 | 0.100 |

DTW Records : 52
Specific Capacity : 5.3 l/s/m

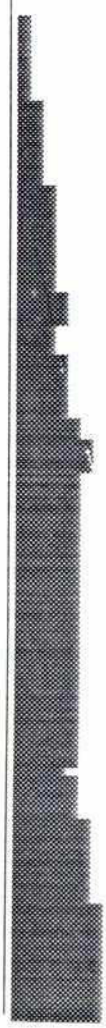
Screen Length : 34 m
Permeability : 22.0 m/d

Depth 86 m

*Data Source : BADC / Deep Tubewell II Project*

District : 55 - COMILLA

Thana : 386 - BURICHANG



| Depth (m) | Br. % | CL % | FS % | MS % | CS % | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|
| | 7 | 93 | | | | Brown Clay | 14 | 0.022 | 0.022 |
| 2 | 7 | 93 | | | | | 14 | 0.022 | 0.022 |
| | 7 | 93 | | | | | 14 | 0.022 | 0.022 |
| 4 | 7 | 86 | 7 | | | | 14 | 0.027 | 0.023 |
| | 7 | 86 | 7 | | | | 14 | 0.027 | 0.024 |
| 6 | 7 | 86 | 7 | | | | 14 | 0.027 | 0.025 |
| | 14 | 64 | 36 | | | | 14 | 0.045 | 0.028 |
| 8 | 14 | 64 | 36 | | | | 14 | 0.045 | 0.030 |
| | 14 | 64 | 36 | | | | 14 | 0.045 | 0.031 |
| 10 | 21 | 50 | 50 | | | | 14 | 0.055 | 0.034 |
| | 21 | 50 | 50 | | | | 14 | 0.055 | 0.036 |
| 12 | 21 | 50 | 50 | | | | 14 | 0.055 | 0.037 |
| | 14 | 43 | 50 | 7 | | Brown Fine SAND | 14 | 0.064 | 0.039 |
| 14 | 14 | 43 | 50 | 7 | | | 14 | 0.064 | 0.041 |
| | 14 | 43 | 50 | 7 | | | 14 | 0.064 | 0.043 |
| 16 | 21 | 43 | 50 | 7 | | | 14 | 0.064 | 0.044 |
| | 21 | 43 | 50 | 7 | | | 14 | 0.064 | 0.045 |
| 18 | 21 | 43 | 50 | 7 | | | 14 | 0.064 | 0.046 |
| | 21 | 50 | 43 | 7 | | Brown Clay | 14 | 0.059 | 0.047 |
| 20 | 21 | 50 | 43 | 7 | | | 14 | 0.059 | 0.048 |
| | 21 | 50 | 43 | 7 | | | 14 | 0.059 | 0.048 |
| 22 | 21 | 50 | 43 | 7 | | | 14 | 0.059 | 0.049 |
| | 21 | 43 | 50 | 7 | | Brown Fine SAND | 14 | 0.064 | 0.049 |
| 24 | 21 | 43 | 50 | 7 | | | 14 | 0.064 | 0.050 |
| | 43 | 21 | 57 | 21 | | | 14 | 0.088 | 0.051 |
| 26 | 43 | 21 | 57 | 21 | | | 14 | 0.088 | 0.053 |
| | 43 | 21 | 57 | 21 | | | 14 | 0.088 | 0.054 |
| 28 | 43 | 29 | 43 | 29 | | | 14 | 0.087 | 0.055 |
| | 43 | 29 | 43 | 29 | | | 14 | 0.087 | 0.056 |
| 30 | 43 | 29 | 43 | 29 | | | 14 | 0.087 | 0.057 |
| | 43 | 29 | 43 | 29 | | | 14 | 0.087 | 0.058 |
| 32 | 43 | 29 | 43 | 29 | | | 14 | 0.087 | 0.059 |
| | 43 | 29 | 43 | 29 | | | 14 | 0.087 | 0.060 |
| 34 | 43 | 21 | 50 | 29 | | | 14 | 0.092 | 0.061 |
| | 43 | 21 | 50 | 29 | | | 14 | 0.092 | 0.062 |
| 36 | 36 | 21 | 43 | 36 | | | 14 | 0.096 | 0.063 |
| | 36 | | 64 | 29 | 7 | | 14 | 0.119 | 0.064 |
| 38 | 36 | | 64 | 29 | 7 | | 14 | 0.119 | 0.066 |
| | 36 | | 64 | 29 | 7 | | 14 | 0.119 | 0.067 |
| 40 | 29 | | 64 | 29 | 7 | | 14 | 0.119 | 0.069 |
| | 29 | | 64 | 29 | 7 | | 14 | 0.119 | 0.070 |
| 42 | 21 | | 50 | 36 | 14 | Grey Fine SAND | 14 | 0.134 | 0.071 |
| | 14 | 7 | 43 | 36 | 14 | | 14 | 0.129 | 0.073 |
| 44 | 14 | 7 | 43 | 36 | 14 | | 14 | 0.129 | 0.074 |
| | 14 | 7 | 43 | 36 | 14 | | 14 | 0.129 | 0.075 |
| 46 | 15 | 8 | 38 | 38 | 15 | | 13 | 0.132 | 0.076 |
| | 15 | 8 | 38 | 38 | 15 | | 13 | 0.132 | 0.078 |
| 48 | 15 | 8 | 38 | 38 | 15 | | 13 | 0.132 | 0.079 |
| | 15 | 8 | 38 | 31 | 23 | | 13 | 0.140 | 0.080 |
| 50 | 15 | 8 | 38 | 31 | 23 | | 13 | 0.140 | 0.081 |
| | 15 | 8 | 38 | 31 | 23 | | 13 | 0.140 | 0.082 |
| 52 | 23 | 8 | 38 | 38 | 15 | | 13 | 0.132 | 0.083 |
| | 23 | 8 | 38 | 38 | 15 | | 13 | 0.132 | 0.084 |
| 54 | 23 | 8 | 31 | 46 | 15 | Grey Medium SAND | 13 | 0.137 | 0.085 |
| | 15 | 8 | 31 | 38 | 23 | | 13 | 0.145 | 0.086 |
| 56 | 15 | 8 | 31 | 38 | 23 | | 13 | 0.145 | 0.087 |
| | 15 | 8 | 31 | 38 | 23 | | 13 | 0.145 | 0.088 |
| 58 | 23 | | 31 | 46 | 23 | | 13 | 0.155 | 0.089 |
| | 23 | | 31 | 46 | 23 | | 13 | 0.155 | 0.091 |
| 60 | 23 | | 31 | 46 | 23 | | 13 | 0.155 | 0.092 |
| | 15 | | 23 | 38 | 38 | | 13 | 0.175 | 0.093 |
| 62 | 15 | | 23 | 38 | 38 | | 13 | 0.175 | 0.094 |
| | 15 | | 23 | 38 | 38 | | 13 | 0.175 | 0.096 |
| 64 | 15 | | 23 | 38 | 38 | | 13 | 0.175 | 0.097 |
| | 17 | | 17 | 42 | 42 | | 12 | 0.182 | 0.098 |
| 66 | 17 | | 17 | 42 | 42 | | 12 | 0.182 | 0.099 |
| | 18 | | 18 | 36 | 45 | Grey Coarse SAND | 11 | 0.185 | 0.101 |
| 68 | 18 | | 9 | 45 | 45 | Grey Medium SAND | 11 | 0.190 | 0.102 |
| | 18 | | 9 | 45 | 45 | | 11 | 0.190 | 0.103 |
| 70 | 18 | | 9 | 45 | 45 | | 11 | 0.190 | 0.104 |
| | 18 | | 18 | 36 | 45 | Grey Coarse SAND | 11 | 0.185 | 0.106 |
| 72 | 18 | | 18 | 36 | 45 | | 11 | 0.185 | 0.107 |
| | 18 | | 18 | 36 | 45 | | 11 | 0.185 | 0.108 |
| 74 | 18 | 9 | 9 | 45 | 36 | Grey Medium SAND | 11 | 0.169 | 0.109 |
| | 18 | 9 | 9 | 45 | 36 | | 11 | 0.169 | 0.109 |
| 76 | 18 | 9 | 9 | 45 | 36 | | 11 | 0.169 | 0.110 |
| | 18 | 9 | 9 | 45 | 36 | | 11 | 0.169 | 0.111 |
| 78 | 18 | 9 | 9 | 45 | 36 | | 11 | 0.169 | 0.112 |
| | 18 | 9 | 9 | 45 | 36 | | 11 | 0.169 | 0.112 |
| 80 | 20 | 10 | | 40 | 50 | Grey Coarse SAND | 10 | 0.187 | 0.113 |
| | 20 | 10 | | 40 | 50 | | 10 | 0.187 | 0.114 |
| 82 | 20 | 10 | | 40 | 50 | | 10 | 0.187 | 0.115 |
| | 22 | 11 | | 33 | 56 | | 9 | 0.191 | 0.116 |
| 84 | 22 | 11 | | 33 | 56 | | 9 | 0.191 | 0.117 |
| | 22 | 11 | | 33 | 56 | | 9 | 0.191 | 0.118 |

DTW Records : 14
Specific Capacity : **.* l/s/m

Screen Length : 28 m
Permeability : **.* m/d

Depth 84 m

*Data Source : BADC / Deep Tubewell II Project*

District : 55 - COMILLA

Thana : 382 - DAUDKANDI

| Depth (m) | Br. % | CL % | FS % | MS % | CS % | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|
| | | 70 | 30 | | | Grey Clay | 10 | 0.041 | 0.041 |
| 2 | | 70 | 30 | | | | 10 | 0.041 | 0.041 |
| | | 60 | 40 | | | | 10 | 0.048 | 0.043 |
| 4 | | 40 | 60 | | | Grey Fine SAND | 10 | 0.062 | 0.048 |
| | | 40 | 60 | | | | 10 | 0.062 | 0.051 |
| 6 | | 40 | 60 | | | | 10 | 0.062 | 0.053 |
| | 10 | 30 | 70 | | | | 10 | 0.069 | 0.055 |
| 8 | 10 | 30 | 70 | | | | 10 | 0.069 | 0.057 |
| | 10 | 30 | 70 | | | | 10 | 0.069 | 0.058 |
| 10 | 10 | 20 | 80 | | | | 10 | 0.076 | 0.060 |
| | 10 | 10 | 90 | | | | 10 | 0.083 | 0.062 |
| 12 | 10 | 10 | 90 | | | | 10 | 0.083 | 0.064 |
| | 10 | 10 | 80 | 10 | | | 10 | 0.089 | 0.066 |
| 14 | 10 | 10 | 80 | 10 | | | 10 | 0.089 | 0.067 |
| | 10 | 10 | 80 | 10 | | | 10 | 0.089 | 0.069 |
| 16 | 10 | 10 | 80 | 10 | | | 10 | 0.089 | 0.070 |
| | 10 | 10 | 80 | 10 | | | 10 | 0.089 | 0.071 |
| 18 | 10 | 10 | 80 | 10 | | | 10 | 0.089 | 0.072 |
| | 20 | 10 | 80 | 10 | | | 10 | 0.089 | 0.073 |
| 20 | 20 | 10 | 80 | 10 | | | 10 | 0.089 | 0.074 |
| | 20 | 10 | 80 | 10 | | | 10 | 0.089 | 0.075 |
| 22 | 20 | 20 | 70 | 10 | | | 10 | 0.082 | 0.075 |
| | 20 | 20 | 70 | 10 | | | 10 | 0.082 | 0.075 |
| 24 | 10 | 30 | 50 | 20 | | | 10 | 0.081 | 0.075 |
| | 10 | 20 | 50 | 30 | | | 10 | 0.094 | 0.076 |
| 26 | 10 | 20 | 50 | 30 | | | 10 | 0.094 | 0.077 |
| | 10 | 10 | 50 | 40 | | | 10 | 0.107 | 0.078 |
| 28 | 10 | | 50 | 50 | | | 10 | 0.120 | 0.080 |
| | 10 | | 50 | 40 | 10 | | 10 | 0.130 | 0.081 |
| 30 | 10 | | 50 | 40 | 10 | | 10 | 0.130 | 0.083 |
| | 10 | 10 | 40 | 40 | 10 | | 10 | 0.123 | 0.084 |
| 32 | 10 | 10 | 40 | 50 | | Grey Medium SAND | 10 | 0.113 | 0.085 |
| | 10 | 20 | 30 | 50 | | | 10 | 0.106 | 0.086 |
| 34 | 10 | 20 | 30 | 50 | | | 10 | 0.106 | 0.086 |
| | 10 | 20 | 20 | 60 | | | 10 | 0.112 | 0.087 |
| 36 | 10 | 20 | 20 | 60 | | | 10 | 0.112 | 0.088 |
| | 10 | 10 | 30 | 60 | | | 10 | 0.119 | 0.089 |
| 38 | 10 | 10 | 30 | 60 | | | 10 | 0.119 | 0.089 |
| | 10 | 10 | 30 | 60 | | | 10 | 0.119 | 0.090 |
| 40 | 10 | 10 | 20 | 70 | | | 10 | 0.125 | 0.091 |
| | 10 | | 20 | 80 | | | 10 | 0.138 | 0.092 |
| 42 | 10 | | 20 | 80 | | | 10 | 0.138 | 0.093 |
| | 10 | 10 | 20 | 70 | | | 10 | 0.125 | 0.094 |
| 44 | 10 | 10 | 40 | 50 | | | 10 | 0.113 | 0.094 |
| | 10 | 10 | 40 | 50 | | | 10 | 0.113 | 0.095 |
| 46 | 10 | 20 | 40 | 40 | | Grey Fine SAND | 10 | 0.100 | 0.095 |
| | 10 | 20 | 40 | 40 | | | 10 | 0.100 | 0.095 |
| 48 | 10 | 20 | 40 | 40 | | | 10 | 0.100 | 0.095 |
| | 10 | 30 | 30 | 40 | | Grey Medium SAND | 10 | 0.093 | 0.095 |
| 50 | 10 | 30 | 30 | 40 | | | 10 | 0.093 | 0.095 |
| | 10 | 30 | 30 | 40 | | | 10 | 0.093 | 0.095 |
| 52 | 20 | 40 | 20 | 40 | | Grey Clay | 10 | 0.086 | 0.095 |
| | 20 | 40 | 20 | 40 | | | 10 | 0.086 | 0.095 |
| 54 | 20 | 50 | 20 | 30 | | | 10 | 0.073 | 0.094 |
| | 20 | 50 | 10 | 30 | 10 | | 10 | 0.089 | 0.094 |
| 56 | 20 | 50 | 10 | 30 | 10 | | 10 | 0.089 | 0.094 |
| | 30 | 50 | | 40 | 10 | | 10 | 0.095 | 0.094 |
| 58 | 30 | 50 | | 40 | 10 | | 10 | 0.095 | 0.094 |
| | 40 | 40 | | 50 | 10 | Grey Medium SAND | 10 | 0.108 | 0.094 |
| 60 | 40 | 40 | | 50 | 10 | | 10 | 0.108 | 0.095 |
| | 40 | 40 | | 50 | 10 | | 10 | 0.108 | 0.095 |
| 62 | 40 | 40 | | 50 | 10 | | 10 | 0.108 | 0.095 |
| | 30 | 30 | | 60 | 10 | | 10 | 0.121 | 0.095 |
| 64 | 30 | 30 | | 60 | 10 | | 10 | 0.121 | 0.096 |
| | 30 | 20 | | 70 | 10 | | 10 | 0.134 | 0.096 |
| 66 | 30 | 10 | | 80 | 10 | | 10 | 0.147 | 0.097 |
| | 30 | 10 | | 80 | 10 | | 10 | 0.147 | 0.098 |
| 68 | 20 | 10 | | 90 | | | 10 | 0.137 | 0.099 |
| | 20 | 10 | | 90 | | | 10 | 0.137 | 0.099 |
| 70 | 30 | | | 100 | | | 10 | 0.150 | 0.100 |
| | 30 | | | 100 | | | 10 | 0.150 | 0.100 |
| 72 | 30 | | | 100 | | | 10 | 0.150 | 0.101 |
| | 40 | | | 100 | | | 10 | 0.150 | 0.102 |
| 74 | 30 | | | 100 | | | 10 | 0.150 | 0.103 |
| | 30 | | | 100 | | | 10 | 0.150 | 0.103 |
| 76 | 30 | | | 100 | | | 10 | 0.150 | 0.104 |
| | 30 | | | 100 | | | 10 | 0.150 | 0.104 |
| 78 | 30 | | | 100 | | | 10 | 0.150 | 0.105 |
| | 30 | | | 100 | | | 10 | 0.150 | 0.106 |
| 80 | 30 | | | 100 | | | 10 | 0.150 | 0.106 |
| | 30 | 10 | | 90 | | | 10 | 0.137 | 0.106 |
| 82 | 20 | 10 | | 90 | | | 10 | 0.137 | 0.107 |
| | 10 | 20 | | 80 | | | 10 | 0.124 | 0.107 |
| 84 | 10 | 20 | | 80 | | | 10 | 0.124 | 0.107 |
| | 10 | 20 | | 80 | | | 10 | 0.124 | 0.107 |

DTW Records : 10
Specific Capacity : 6.7 l/s/m

Screen Length : 31 m
Permeability : 30.4 m/d

Depth 87 m

*Data Source : BADC / Deep Tubewell II Project*

District : 55 - COMILLA

Thana : 384 - DEBIDWAR

| Depth (m) | Br. % | CL % | FS % | MS % | CS % | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|
| | 38 | 100 | | | | Grey Clay | 8 | 0.020 | 0.020 |
| 2 | 38 | 100 | | | | | 8 | 0.020 | 0.020 |
| | 38 | 100 | | | | | 8 | 0.020 | 0.020 |
| 4 | 13 | 88 | 13 | | | | 8 | 0.029 | 0.022 |
| | 13 | 88 | 13 | | | | 8 | 0.029 | 0.024 |
| 6 | 13 | 88 | 13 | | | | 8 | 0.029 | 0.024 |
| | 13 | 88 | 13 | | | | 8 | 0.029 | 0.025 |
| 8 | 13 | 88 | 13 | | | | 8 | 0.029 | 0.025 |
| | 25 | 75 | 25 | | | | 8 | 0.038 | 0.027 |
| 10 | 25 | 75 | 25 | | | | 8 | 0.038 | 0.028 |
| | 25 | 75 | 25 | | | | 8 | 0.038 | 0.029 |
| 12 | 25 | 75 | 25 | | | | 8 | 0.038 | 0.029 |
| | 25 | 75 | 25 | | | | 8 | 0.038 | 0.030 |
| 14 | 13 | 50 | 50 | | | | 8 | 0.055 | 0.032 |
| | 13 | 50 | 50 | | | | 8 | 0.055 | 0.033 |
| 16 | 13 | 50 | 50 | | | | 8 | 0.055 | 0.035 |
| | 13 | 38 | 50 | 13 | | Grey Fine SAND | 8 | 0.071 | 0.037 |
| 18 | 25 | 50 | 38 | 13 | | Grey Clay | 8 | 0.063 | 0.038 |
| | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.040 |
| 20 | 25 | 25 | 75 | | | Grey Fine SAND | 8 | 0.073 | 0.041 |
| | 25 | 25 | 63 | 13 | | | 8 | 0.080 | 0.043 |
| 22 | 25 | 25 | 63 | 13 | | | 8 | 0.080 | 0.045 |
| | 13 | 25 | 63 | 13 | | | 8 | 0.080 | 0.046 |
| 24 | 13 | 38 | 50 | 13 | | | 8 | 0.071 | 0.047 |
| | 13 | 38 | 50 | 13 | | | 8 | 0.071 | 0.048 |
| 26 | 25 | 50 | 38 | 13 | | Grey Clay | 8 | 0.063 | 0.049 |
| | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.049 |
| 28 | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.050 |
| | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.050 |
| 30 | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.051 |
| | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.051 |
| 32 | 38 | 63 | 38 | | | | 8 | 0.046 | 0.051 |
| | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.051 |
| 34 | 25 | 50 | 38 | 13 | | | 8 | 0.063 | 0.052 |
| | 38 | 38 | 50 | 13 | | Grey Fine SAND | 8 | 0.071 | 0.052 |
| 36 | 38 | 38 | 50 | 13 | | | 8 | 0.071 | 0.053 |
| | 38 | 38 | 50 | 13 | | | 8 | 0.071 | 0.053 |
| 38 | 38 | 38 | 50 | 13 | | | 8 | 0.071 | 0.054 |
| | 38 | 38 | 50 | 13 | | | 8 | 0.071 | 0.054 |
| 40 | 13 | 63 | 25 | 13 | | Grey Clay | 8 | 0.054 | 0.054 |
| | 38 | 63 | 25 | 13 | | | 8 | 0.054 | 0.054 |
| 42 | 38 | 63 | 25 | 13 | | | 8 | 0.054 | 0.054 |
| | 25 | 100 | | | | | 8 | 0.020 | 0.053 |
| 44 | 63 | 63 | 38 | | | Brown Clay | 8 | 0.046 | 0.053 |
| | 50 | 50 | 38 | 13 | | Mixed Clay | 8 | 0.063 | 0.053 |
| 46 | 50 | 38 | 50 | 13 | | Mixed Fine SAND | 8 | 0.071 | 0.054 |
| | 38 | 25 | 63 | 13 | | Grey Fine SAND | 8 | 0.080 | 0.054 |
| 48 | 38 | 25 | 63 | 13 | | | 8 | 0.080 | 0.055 |
| | 25 | 25 | 63 | | 13 | | 8 | 0.093 | 0.056 |
| 50 | 13 | 50 | 50 | | | Grey Clay | 8 | 0.055 | 0.056 |
| | 13 | 50 | 50 | | | | 8 | 0.055 | 0.056 |
| 52 | | 63 | 38 | | | | 8 | 0.046 | 0.055 |
| | | 75 | 25 | | | | 8 | 0.038 | 0.055 |
| 54 | | 63 | 38 | | | | 8 | 0.046 | 0.055 |
| | | 38 | 38 | 25 | | | 8 | 0.079 | 0.055 |
| 56 | | 25 | 50 | 25 | | Grey Fine SAND | 8 | 0.088 | 0.056 |
| | | 25 | 50 | 25 | | | 8 | 0.088 | 0.056 |
| 58 | | 13 | 50 | 25 | 13 | | 8 | 0.116 | 0.057 |
| | | 13 | 25 | 50 | 13 | Grey Medium SAND | 8 | 0.131 | 0.059 |
| 60 | | 13 | 25 | 50 | 13 | | 8 | 0.131 | 0.060 |
| | | | 13 | 75 | 13 | | 8 | 0.155 | 0.061 |
| 62 | | | 25 | 63 | 13 | | 8 | 0.148 | 0.063 |
| | | 13 | 25 | 63 | | | 8 | 0.119 | 0.064 |
| 64 | | 13 | 25 | 63 | | | 8 | 0.119 | 0.065 |
| | | | 25 | 75 | | | 8 | 0.135 | 0.066 |
| 66 | | | 25 | 75 | | | 8 | 0.135 | 0.067 |
| | | 25 | 25 | 50 | | | 8 | 0.103 | 0.067 |
| 68 | | 13 | 13 | 75 | | | 8 | 0.126 | 0.068 |
| | | 13 | 13 | 75 | | | 8 | 0.126 | 0.069 |
| 70 | | 13 | | 88 | | | 8 | 0.134 | 0.070 |
| | | 13 | | 75 | 13 | | 8 | 0.146 | 0.071 |
| 72 | | 13 | | 75 | 13 | | 8 | 0.146 | 0.072 |
| | | 13 | | 75 | 13 | | 8 | 0.146 | 0.073 |
| 74 | | 13 | | 75 | 13 | | 8 | 0.146 | 0.074 |
| | | 13 | | 75 | 13 | | 8 | 0.146 | 0.075 |
| 76 | | 13 | | 75 | 13 | | 8 | 0.146 | 0.076 |
| | | | | 100 | | | 8 | 0.150 | 0.077 |
| 78 | | | | 100 | | | 8 | 0.150 | 0.078 |
| | | | 13 | 88 | | | 8 | 0.143 | 0.079 |
| 80 | | | 13 | 88 | | | 8 | 0.143 | 0.079 |
| | | | 13 | 88 | | | 8 | 0.143 | 0.080 |
| 82 | | | 13 | 88 | | | 8 | 0.143 | 0.081 |
| | | | 13 | 88 | | | 8 | 0.143 | 0.082 |
| 84 | | 13 | 13 | 75 | | | 8 | 0.126 | 0.082 |
| | | 13 | 13 | 75 | | | 8 | 0.126 | 0.083 |

DTW Records : 8
Specific Capacity : 5.1 l/s/m

Screen Length : 33 m
Permeability : 22.1 m/d

Depth 104 m

*Data Source : BADC / Deep Tubewell II Project*

District : 55 - COMILLA

Thana : 381 - HOMNA

| Depth (m) | Screen Probab-ility | Br. % | CL % | FS % | MS % | CS % | Graphic Log | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | | | | | Clay | 3 | 0.020 | 0.020 |
| 2 | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| 4 | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| 6 | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| 8 | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | | 100 | | | | | | 3 | 0.020 | 0.020 |
| 10 | | 33 | 100 | | | | | Brown Clay | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 12 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 14 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 16 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 18 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 20 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 22 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 24 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 26 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 28 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 30 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| 32 | | 33 | 100 | | | | | | 3 | 0.020 | 0.020 |
| | | 67 | 67 | 33 | | | | | 3 | 0.043 | 0.021 |
| 34 | | 67 | 33 | 67 | | | | Brown Fine SAND | 3 | 0.067 | 0.022 |
| | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.023 |
| 36 | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.025 |
| | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.026 |
| 38 | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.027 |
| | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.028 |
| 40 | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.029 |
| | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.030 |
| 42 | | 67 | 33 | 67 | | | | | 3 | 0.067 | 0.031 |
| | | 67 | | 100 | | | | | 3 | 0.090 | 0.032 |
| 44 | | 67 | | 100 | | | | | 3 | 0.090 | 0.033 |
| | | 67 | | 100 | | | | | 3 | 0.090 | 0.035 |
| 46 | | 67 | | 100 | | | | | 3 | 0.090 | 0.036 |
| | | 67 | | 100 | | | | | 3 | 0.090 | 0.037 |
| 48 | | 67 | | 100 | | | | | 3 | 0.090 | 0.038 |
| | | 67 | | 100 | | | | | 3 | 0.090 | 0.039 |
| 50 | | 67 | | 100 | | | | | 3 | 0.090 | 0.040 |
| | | 67 | | 100 | | | | | 3 | 0.090 | 0.041 |
| 52 | | 67 | | 100 | | | | | 3 | 0.090 | 0.042 |
| | | 67 | | 100 | | | | | 3 | 0.090 | 0.043 |
| 54 | | 67 | | 100 | | | | | 3 | 0.090 | 0.044 |
| | | | | 100 | | | | Grey Fine SAND | 3 | 0.090 | 0.045 |
| 56 | | | | 100 | | | | | 3 | 0.090 | 0.045 |
| | | | | 100 | | | | | 3 | 0.090 | 0.046 |
| 58 | | | | 100 | | | | | 3 | 0.090 | 0.047 |
| | | | | 100 | | | | | 3 | 0.090 | 0.048 |
| 60 | | | | 100 | | | | | 3 | 0.090 | 0.048 |
| | | | | 100 | | | | | 3 | 0.090 | 0.049 |
| 62 | | | | 100 | | | | | 3 | 0.090 | 0.050 |
| | | | | 100 | | | | | 3 | 0.090 | 0.050 |
| 64 | | | | 100 | | | | | 3 | 0.090 | 0.051 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.052 |
| 66 | | | | 67 | 33 | | | | 3 | 0.110 | 0.053 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.054 |
| 68 | | | | 67 | 33 | | | | 3 | 0.110 | 0.054 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.055 |
| 70 | | | | 67 | 33 | | | | 3 | 0.110 | 0.056 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.057 |
| 72 | | | | 67 | 33 | | | | 3 | 0.110 | 0.058 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.058 |
| 74 | | | | 67 | 33 | | | | 3 | 0.110 | 0.059 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.060 |
| 76 | | | | 67 | 33 | | | | 3 | 0.110 | 0.060 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.061 |
| 78 | | | | 67 | 33 | | | | 3 | 0.110 | 0.062 |
| | | | | 67 | 33 | | | | 3 | 0.110 | 0.062 |
| 80 | | | | | 100 | | | Grey Medium SAND | 3 | 0.150 | 0.063 |
| | | | | | 100 | | | | 3 | 0.150 | 0.064 |
| 82 | | | | | 100 | | | | 3 | 0.150 | 0.065 |
| | | | | | 100 | | | | 3 | 0.150 | 0.066 |
| 84 | | | | | 100 | | | | 3 | 0.150 | 0.067 |
| | | | | | 100 | | | | 3 | 0.150 | 0.068 |

DTW Records : 3
Specific Capacity : 4.4 l/s/m

Screen Length : 27 m
Permeability : 22.4 m/d

Depth 104 m

*Data Source : BADC / Deep Tubewell II Project*

District : 55 - COMILLA

Thana : 383 - MURADNAGAR

| Depth (m) | Br. % | CL % | FS % | MS % | CS % | Lithology | Nr of Records m/d | Layer Specific Yield | Integrated Specific Yield |
|---|---|---|---|---|---|---|---|---|---|
| | 14 | 94 | 6 | | | Grey Clay | 49 | 0.024 | 0.024 |
| 2 | 14 | 94 | 6 | | | | 49 | 0.024 | 0.024 |
| | 14 | 94 | 6 | | | | 49 | 0.024 | 0.024 |
| 4 | 6 | 65 | 35 | | | | 49 | 0.044 | 0.029 |
| | 8 | 63 | 37 | | | | 49 | 0.046 | 0.033 |
| 6 | 6 | 59 | 41 | | | | 49 | 0.049 | 0.035 |
| | 6 | 51 | 49 | | | | 49 | 0.054 | 0.038 |
| 8 | 6 | 41 | 59 | | | Grey Fine SAND | 49 | 0.061 | 0.041 |
| | 6 | 35 | 65 | | | | 49 | 0.066 | 0.044 |
| 10 | 6 | 31 | 69 | | | | 49 | 0.069 | 0.046 |
| | 6 | 27 | 73 | | | | 49 | 0.071 | 0.048 |
| 12 | 4 | 24 | 76 | | | | 49 | 0.073 | 0.050 |
| | 2 | 24 | 76 | | | | 49 | 0.073 | 0.052 |
| 14 | 2 | 27 | 71 | 2 | | | 49 | 0.073 | 0.054 |
| | 2 | 31 | 67 | 2 | | | 49 | 0.070 | 0.055 |
| 16 | 2 | 24 | 73 | 2 | | | 49 | 0.074 | 0.056 |
| | 2 | 29 | 69 | 2 | | | 49 | 0.071 | 0.057 |
| 18 | 2 | 31 | 67 | 2 | | | 49 | 0.070 | 0.058 |
| | 2 | 22 | 69 | 6 | | | 49 | 0.077 | 0.059 |
| 20 | 2 | 22 | 69 | 6 | | | 49 | 0.077 | 0.060 |
| | 2 | 24 | 67 | 6 | | | 49 | 0.076 | 0.060 |
| 22 | 6 | 22 | 67 | 8 | | | 49 | 0.078 | 0.061 |
| | 6 | 24 | 63 | 10 | | | 49 | 0.078 | 0.062 |
| 24 | 10 | 24 | 65 | 10 | | | 49 | 0.079 | 0.063 |
| | 14 | 18 | 69 | 12 | | | 49 | 0.084 | 0.063 |
| 26 | 16 | 16 | 65 | 18 | | | 49 | 0.090 | 0.064 |
| | 14 | 14 | 55 | 29 | | | 49 | 0.096 | 0.066 |
| 28 | 14 | 12 | 53 | 33 | | | 49 | 0.100 | 0.067 |
| | 14 | 16 | 53 | 29 | | | 49 | 0.095 | 0.068 |
| 30 | 16 | 16 | 49 | 33 | | | 49 | 0.097 | 0.069 |
| | 18 | 20 | 49 | 31 | | | 49 | 0.094 | 0.070 |
| 32 | 18 | 20 | 53 | 27 | | | 49 | 0.092 | 0.070 |
| | 18 | 24 | 51 | 24 | | | 49 | 0.088 | 0.071 |
| 34 | 18 | 27 | 41 | 33 | | | 49 | 0.091 | 0.071 |
| | 18 | 24 | 41 | 35 | | | 49 | 0.094 | 0.072 |
| 36 | 16 | 27 | 37 | 37 | | | 49 | 0.093 | 0.073 |
| | 18 | 24 | 39 | 35 | 2 | | 49 | 0.097 | 0.073 |
| 38 | 18 | 33 | 33 | 33 | 2 | Grey Clay | 49 | 0.090 | 0.074 |
| | 18 | 33 | 35 | 31 | 2 | Grey Fine SAND | 49 | 0.089 | 0.074 |
| 40 | 22 | 37 | 37 | 24 | 2 | Grey Clay | 49 | 0.082 | 0.074 |
| | 22 | 41 | 35 | 20 | 4 | | 49 | 0.080 | 0.074 |
| 42 | 22 | 39 | 33 | 24 | 4 | | 49 | 0.084 | 0.075 |
| | 20 | 45 | 33 | 18 | 4 | | 49 | 0.076 | 0.075 |
| 44 | 20 | 45 | 31 | 22 | 2 | | 49 | 0.075 | 0.075 |
| | 18 | 39 | 31 | 29 | 2 | | 49 | 0.083 | 0.075 |
| 46 | 18 | 37 | 33 | 29 | 2 | | 49 | 0.085 | 0.075 |
| | 20 | 35 | 39 | 22 | 4 | Grey Fine SAND | 49 | 0.086 | 0.075 |
| 48 | 20 | 33 | 41 | 22 | 4 | | 49 | 0.087 | 0.076 |
| | 20 | 35 | 33 | 29 | 4 | Grey Clay | 49 | 0.089 | 0.076 |
| 50 | 20 | 31 | 35 | 31 | 4 | Grey Fine SAND | 49 | 0.093 | 0.076 |
| | 22 | 29 | 35 | 33 | 4 | | 49 | 0.096 | 0.077 |
| 52 | 20 | 27 | 35 | 37 | 2 | Grey Medium SAND | 49 | 0.097 | 0.077 |
| | 24 | 24 | 37 | 39 | | | 49 | 0.096 | 0.077 |
| 54 | 27 | 22 | 33 | 45 | | | 49 | 0.101 | 0.078 |
| | 29 | 18 | 35 | 47 | | | 49 | 0.105 | 0.078 |
| 56 | 29 | 18 | 35 | 47 | | | 49 | 0.105 | 0.079 |
| | 33 | 16 | 35 | 47 | 2 | | 49 | 0.110 | 0.079 |
| 58 | 33 | 12 | 33 | 53 | 2 | | 49 | 0.117 | 0.080 |
| | 33 | 12 | 37 | 49 | 2 | | 49 | 0.114 | 0.081 |
| 60 | 33 | 12 | 39 | 49 | | | 49 | 0.111 | 0.081 |
| | 35 | 10 | 37 | 53 | | | 49 | 0.115 | 0.082 |
| 62 | 35 | 6 | 29 | 65 | | | 49 | 0.125 | 0.082 |
| | 35 | 4 | 24 | 71 | | | 49 | 0.130 | 0.083 |
| 64 | 33 | 2 | 24 | 71 | 2 | | 49 | 0.135 | 0.084 |
| | 33 | 4 | 20 | 71 | 4 | | 49 | 0.137 | 0.085 |
| 66 | 31 | 6 | 18 | 71 | 4 | | 49 | 0.135 | 0.085 |
| | 31 | 6 | 16 | 73 | 4 | | 49 | 0.136 | 0.086 |
| 68 | 35 | 6 | 16 | 73 | 4 | | 49 | 0.136 | 0.087 |
| | 37 | 6 | 22 | 67 | 4 | | 49 | 0.133 | 0.088 |
| 70 | 39 | 4 | 24 | 65 | 6 | | 49 | 0.136 | 0.088 |
| | 38 | 2 | 29 | 63 | 6 | | 48 | 0.136 | 0.089 |
| 72 | 38 | 2 | 31 | 63 | 4 | | 48 | 0.133 | 0.090 |
| | 38 | 2 | 29 | 65 | 4 | | 48 | 0.134 | 0.090 |
| 74 | 33 | 2 | 27 | 67 | 4 | | 48 | 0.135 | 0.091 |
| | 30 | 2 | 26 | 67 | 4 | | 46 | 0.136 | 0.091 |
| 76 | 30 | 2 | 24 | 70 | 4 | | 46 | 0.137 | 0.092 |
| | 30 | 2 | 26 | 70 | 2 | | 46 | 0.134 | 0.093 |
| 78 | 28 | 2 | 17 | 80 | | | 46 | 0.137 | 0.093 |
| | 28 | 2 | 20 | 78 | | | 46 | 0.135 | 0.094 |
| 80 | 29 | | 24 | 76 | | | 45 | 0.135 | 0.094 |
| | 27 | | 24 | 76 | | | 45 | 0.135 | 0.095 |
| 82 | 27 | | 27 | 73 | | | 45 | 0.134 | 0.095 |
| | 30 | | 27 | 73 | | | 44 | 0.134 | 0.096 |
| 84 | 30 | 2 | 25 | 73 | | | 44 | 0.132 | 0.096 |
| | 28 | 2 | 23 | 74 | | | 43 | 0.133 | 0.097 |

DTW Records : 49
Specific Capacity : 5.6 l/s/m

Screen Length : 34 m
Permeability : 23.2 m/d

Depth 95 m

Data Source : BADC / Deep Tubewell II Project

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Appendix C.V

# OUTPUT FROM THE GROUNDWATER MODELS

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**Sample Input and Output of the Single Cell Thana Model (SCTM)**

UB 6

**File : SE_GH130.DAT** (Debidwar Aquifer Geometry)

```
4.8 -18.2 -29.2 -44.2 -104
20 22 0.1 0.1 0.0005 0.10
0.020 0.020 0.020 0.029 0.029 0.029 0.029 0.029 0.038 0.038
0.038 0.038 0.038 0.055 0.055 0.055 0.071 0.063 0.063 0.073
0.080 0.080
1 0.050 0.0100 0.0250 50.4 42.3  8.7
2 0.050 0.0060 0.0100 50.9 46.1  9.2
3 0.050 0.0100 0.0150 50.3 42.0  9.8
4 0.050 0.0060 0.0150 47.5 37.2 18.5
5 0.050 0.0040 0.0050 44.5 41.1 25.5
6 0.025 0.0020 0.0050 54.0 51.9 32.1
7 0.025 0.0020 0.0050 50.7 46.3 25.7
8 0.050 0.0060 0.0150 43.2 33.8 18.0
1  6  100.00
2  6  100.00
3  24  90.10
4  27  24.76
5  24  97.03
6  47  54.46
7  246 40.53
8  6  100.00
9  6  100.00
9999
```

**File : SE_LT130.DAT** (Debidwar land Type Distribution)

```
18
'Debidwar','Comilla',235
0.1397
 1.02  0.82  2.75 40.08 18.07 11.50 10.02  1.77  6.83  7.14
 0 0 0 0 0 0 0 0 0 0
   0.      0. 21375.     0.    925.     0.     0.     0.
   0.      0.     0.     0.   1970. 42065.  1970.     0.
 9999
0.1397
 1.02  0.82  2.75 40.08 18.07 11.50 10.02  1.77  6.83  7.14
 0 0 0 0 0 0 0 0 0 0
   0.      0. 21375.     0.    925.     0.     0.     0.
   0.      0.     0.     0.   1970. 42065.  1970.     0.
 9999
0.1397
 1.02  0.82  2.75 40.08 18.07 11.50 10.02  1.77  6.83  7.14
 0 0 0 0 0 0 0 0 0 0
   0.      0. 21375.     0.    925.     0.     0.     0.
   0.      0.     0.     0.   1970. 42065.  1970.     0.
 9999

       etc, etc for 17 years
```

**File : SE_FL130.DAT** (Debidwar Flooding Depths)

```
1 2 3 4 5 6
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
9999
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
9999
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.10 0.40
 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.20 0.05 0.00
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
9999
 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.10 0.40 0.70 1.00
 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.80 0.65 0.40
 0.20 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
9999
 0.05 0.05 0.05 0.05 0.00 0.00 0.10 0.30 0.60 1.00 1.10 1.60
 1.60 1.60 1.60 1.60 1.60 1.60 1.60 1.60 1.60 1.40 1.25 1.00
 0.80 0.40 0.10 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
9999
 1.00 1.00 1.00 1.00 1.00 1.00 1.10 1.30 1.60 2.00 2.10 2.60
 2.60 2.60 2.60 2.60 2.60 2.60 2.60 2.60 2.60 2.40 2.25 2.00
 1.80 1.40 1.10 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
9999
```

*etc, etc for 17 years*

**File : SE_IP130.DAT** (Debidwar Agricultural and Abstraction Parameters)

```
  1 0.80 0.80 0.00
  2 0.80 0.80 0.00
  3 0.90 0.90 0.00
  4 0.90 0.90 0.00
  5 0.90 0.90 0.00
  6 1.00 1.00 0.00
 0.10 0.15 0.20 0.20 0.20 0.20 0.20 0.20
 0.00 0.15 0.20 0.20 0.20 0.20 0.20 0.20
 0.30 0.30 0.30 0.30 0.30 0.60 0.60 0.60 1.50 2.00 2.00 0.60 0.60 0.30 0.30 0.30
 0.58
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.85 0.60  0.80  0.70  0.05  0.05  0.05  0.50  0.25
9999
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86 0.86
```

*etc, etc for 17 years*

**File : CHECK.OUT** Debidwar

| THANA AREA | SURFACE | BASE SC. | BASE U.AQTD. | BASE L.Aqtd | BASE L.AQTD |
|---|---|---|---|---|---|
| 23500.00 | 4.80 | -18.20 | -29.20 | -44.2 | -104 |

**LOCAL RELIEF CHARACTERISTICS**

LAND CATEGORY

| H | MH | ML | L | B | OW |
|---|---|---|---|---|---|
| 1.04 | 0.44 | -0.16 | -0.76 | -1.36 | -1.96 |

**LAND TYPE PROPORTIONS FOR SEASON : 1**

LAND TYPE

| Hp | Hi | MHp | MHi | MLp | MLi | L | B | OW | HO |
|---|---|---|---|---|---|---|---|---|---|
| 0.01 | 0.01 | 0.03 | 0.40 | 0.18 | 0.11 | 0.10 | 0.02 | 0.07 | 0.07 |

**PROPORTIONS OF LAND TYPES CULTIVABLE FOR SEASON : 1**

LAND TYPE

| Hp | Hi | MHp | MHi | MLp | MLi | L | B | OW | HO |
|---|---|---|---|---|---|---|---|---|---|
| 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.96 | 0.57 | 0.00 | 0.00 |

**CROP DISTRIBUTION OVER LAND TYPE AREAS FOR SEASON : 1**

| LAND TYPE | | AREA | NON-IRRIGATED CROPS (ha) | | | | | | | | | | | | IRRIGATED CROPS (ha) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | B.AUS | T.AUS | T.AMAN | B.AMAN | BORO | JUTE | WHEAT | RABI | S.CANE | ORCHARD | FOREST | GRASS | WHEAT | BORO | T.AUS | T.AMAN |
| 1 | Hp | 240 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 216 | 0 | 216 | 0 |
| 2 | Hi | 193 | 0 | 0 | 173 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 173 | 0 | 0 |
| 3 | MHp | 646 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 65 | 582 | 0 | 582 | 0 |
| 4 | MHi | 9419 | 0 | 0 | 8477 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 942 | 0 | 8477 | 0 | 0 |
| 5 | MLp | 4246 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 425 | 0 | 3822 | 0 | 0 |
| 6 | MLi | 2702 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 270 | 0 | 2432 | 0 | 0 |
| 7 | L | 2355 | 0 | 0 | 0 | 0 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 2119 | 0 | 0 |
| 8 | B | 416 | 0 | 0 | 0 | 0 | 239 | 0 | 0 | 0 | 0 | 0 | 0 | 177 | 0 | 0 | 0 | 0 |
| TOTAL | | 20217 | 0 | 0 | 8650 | 0 | 374 | 0 | 0 | 0 | 0 | 0 | 0 | 2022 | 797 | 17024 | 797 | 0 |

**HYDROGEOLOGICAL CHARACTERISTICS - AQUIFER AND SEMI-CONFINING LAYER**

| AQUIFER | SEMI-CONFINING LAYER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PERMEABILITY | STORAGE COEFFICIENTS | | VERTICAL | SPECIFIC YIELD VALUES FOR UPPER 10 m | | | | | | | | | |
| | CONFINED | UNCONFINED | PERMEABILITY | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 |
| 20.00 | 0.00050 | 0.100 | 0.0500 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 |

**HYDROGEOLOGICAL CHARACTERISTICS - UNSATURATED ZONE AND SOIL SURFACE**

| LAND TYPE | | INFILT. | DEEP PERC. | | SOIL MOISTURE | | | SOIL TYPES AND PERCENTAGE | | | "BUND" HEIGHT | | EFF./GROSS RAIN | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | WET | DRY | SAT. | F.C. | W.P. | 1 | 2 | 3 | WET | DRY | WET | DRY |
| 1 | Hp | 0.0250 | 0.0020 | 0.0050 | 0.54 | 0.52 | 0.32 | C 100 | N.P. | N.P. | 0.10 | 0.00 | 0.80 | 0.80 |
| 2 | Hi | 0.0250 | 0.0020 | 0.0050 | 0.54 | 0.52 | 0.32 | C 100 | N.P. | N.P. | 0.15 | 0.15 | 0.80 | 0.80 |
| 3 | MHp | 0.0500 | 0.0060 | 0.0105 | 0.51 | 0.45 | 0.10 | SiL 90 | SiCL 10 | N.P. | 0.20 | 0.20 | 0.80 | 0.80 |
| 4 | MHi | 0.0310 | 0.0030 | 0.0062 | 0.51 | 0.46 | 0.22 | SiL 24 | SiC 76 | N.P. | 0.20 | 0.20 | 0.80 | 0.80 |
| 5 | MLp | 0.0500 | 0.0060 | 0.0101 | 0.51 | 0.46 | 0.09 | SiL 97 | SiCL 3 | N.P. | 0.20 | 0.20 | 0.90 | 0.90 |
| 6 | MLi | 0.0385 | 0.0042 | 0.0104 | 0.49 | 0.41 | 0.22 | SiCL 54 | SiC 46 | N.P. | 0.20 | 0.20 | 0.90 | 0.90 |
| 7 | L | 0.0482 | 0.0057 | 0.0123 | 0.49 | 0.42 | 0.16 | SiL 40 | SiCL 53 | C 7 | 0.20 | 0.20 | 0.90 | 0.90 |
| 8 | B | 0.0250 | 0.0020 | 0.0050 | 0.54 | 0.52 | 0.32 | C 100 | N.P. | N.P. | 0.20 | 0.20 | 0.90 | 0.90 |
| 9 | OW | 0.0250 | 0.0020 | 0.0050 | 0.54 | 0.52 | 0.32 | C 100 | N.P. | N.P. | 0.00 | 0.00 | 1.00 | 1.00 |

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**Output of the Analytical Model of Upconing**

The following two pages show the output from a spreadsheet formulation of the analytical model of Schmorak and Mercado (1969)[1]. On each page the table applies only to one moment in time, but the graph refers to a range of times. The comment "discharge too high" applies to steady state pumping only.

---

1 "Upconing of fresh water - salt water interface below pumping wells, field study". *Water Resources Research*. vol. 5, nr 6.

## Saline Upconing
**Schmorak & Mercado (1969)**

*EDIT THE SHADED BOXES ONLY*

| | | |
|---|---|---|
| K(h) | 25 | m/d |
| K(v) | 2.5 | m/d |
| Porosity | 0.25 | |
| rho(f) | 1.000 | |
| rho(s) | 1.005 | |
| Time | 100 | days |
| | 0.27 | years |
| Depth to bottom of well | 24 | m |
| Depth to initial interface | 65 | m |
| Initial Separation | 41 | m |
| Discharge | 14 | l/s |
| " | 1209.6 | m3/d |

Density factor
0.005
Calculate parameter GAMMA(u)
0.061

Zp = A1 * A2
Parameter A1 37.5588
Parameter A2 0.0575

***Comments:***
case of upconing of 'heavy' saline water from the lower aquifer

Higher Kv
Deeper well

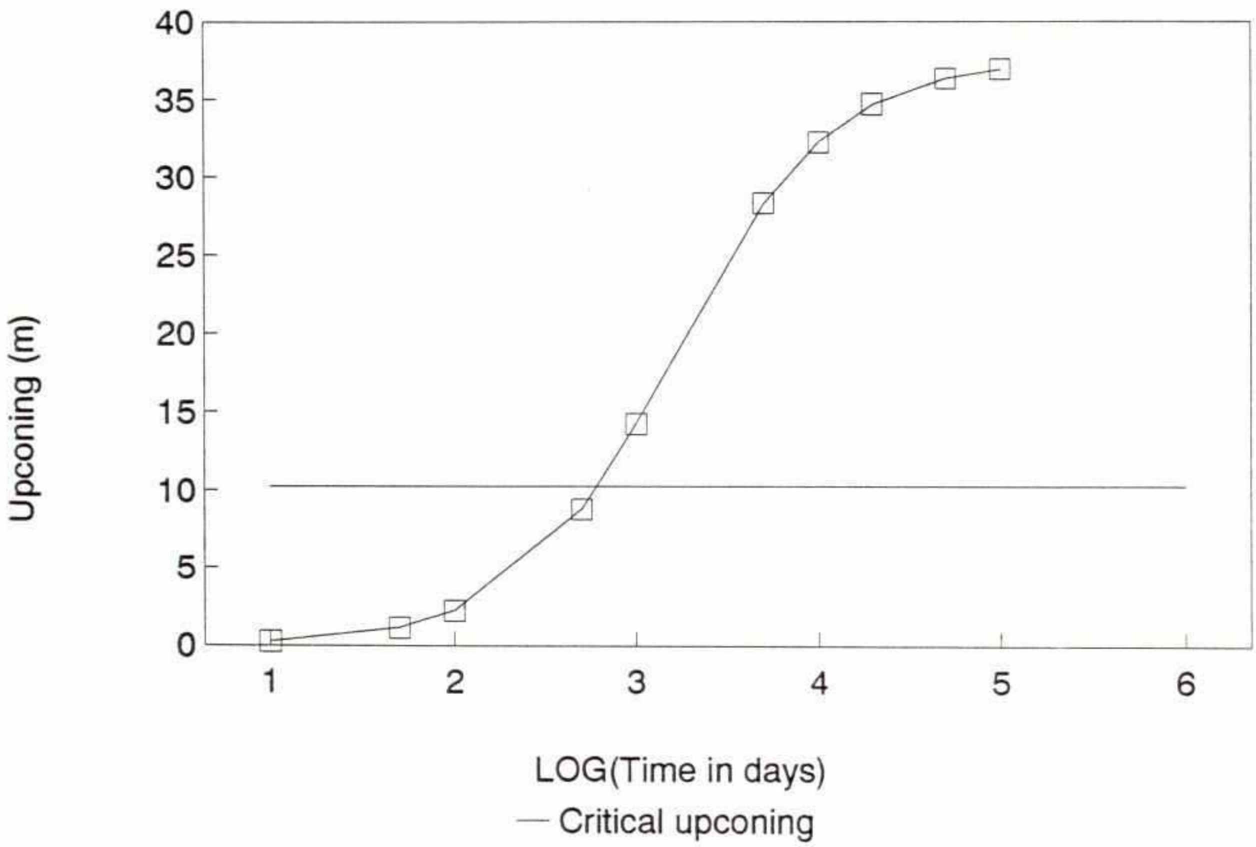
Check against:
Maximum discharge <= **4 l/s**
for steady state ***DISCHARGE TOO HIGH***

**% of max discharge**
**366%**

Critical rise of interface **10.3 m**

***For the the case where r = 0 (i.e. beneath the well)***
**Upconing of interface** **2.159 m**

**Upconing less than critical rise**



## Saline Upconing
**Schmorak & Mercado (1969)**

*EDIT THE SHADED BOXES ONLY*

| | | |
|---|---|---|
| K(h) | **25** | m/d |
| K(v) | **0.5** | m/d |
| Porosity | **0.25** | |
| rho(f) | **1.000** | |
| rho(s) | **1.005** | |
| Time | **100** | days |
| | **0.27** | years |
| Depth to bottom of well | **24** | m |
| Depth to initial interface | **65** | m |
| Initial Separation | 41 | m |
| Discharge | **14** | l/s |
| " | 1209.6 | m3/d |

Density factor
0.005
Calculate parameter GAMMA(u)
0.012

Zp = A1 * A2

| | |
|---|---|
| Parameter A1 | 37.5588 |
| Parameter A2 | 0.0120 |

***Comments:***
case of upconing of 'heavy' saline water from the lower aquifer

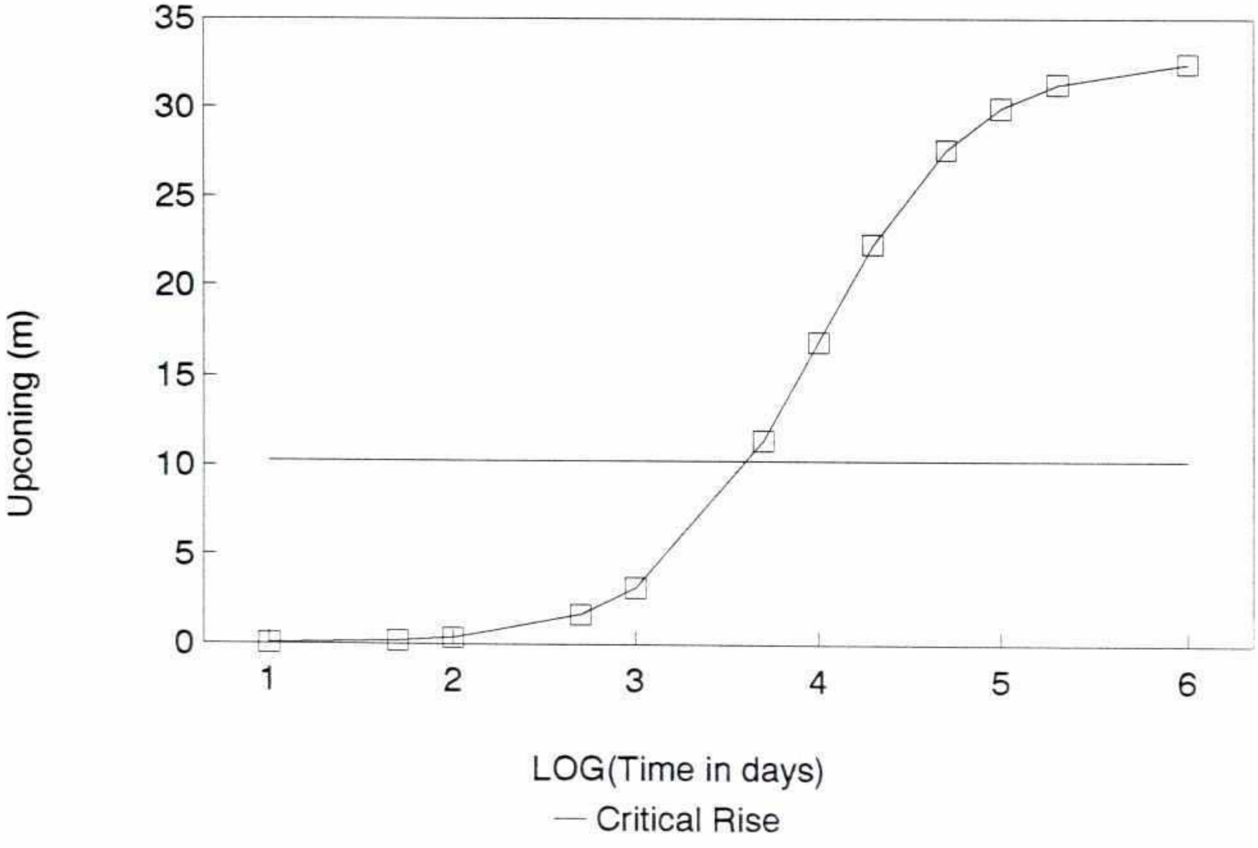
Normal Kv
Shallow well

Check against:
Maximum discharge <= for steady state **4 l/s** ***DISCHARGE TOO HIGH***

**% of max discharge** **366%**

Critical rise of interface **10.3 m**

***For the the case where r = 0 (i.e. beneath the well)***
**Upconing of interface** **0.453 m** **Upconing less than critical rise**



**Output of the SUTRA Solute Transport Model**

The following page shows the grid layout and relative concentrations at each node. The concentrations are expressed as a percentage of the initial maximum concentration of 4,000 mg/l. The nodes are printed in real format, and hence gives a pseudo-section through the aquifer. the input parameters for the model were:

| | Semi-confining layer | Aquifer |
|---|---|---|
| Horizontal permeability | 0.05 | 20 m/d |
| Vertical permeability | 0.05 | 0.5 m/d |
| Longitudinal dispersion coefficient | | 5 m |
| Transverse dispersion coefficient | | 0.1 m |
| Porosity | | 0.25 |
| Specific yield | 0.03 | |
| Initial water level | | 2.5 m |
| Initial interface depth | | 59 m |
| Salinity above interface | | 250 mg/l |
| Salinity below interface | | 4000 mg/l |

| | |
|---|---|
| Well screen position | 12 - 24 m |
| Well discharge | 1200 $m^3$/d |

Initial column spacing : 1 m, with a multiplier of 1.25

| | |
|---|---|
| Row spacing | 4 m |
| Number of time steps | 100 |
| Initial time step | 2 days |

## Relative Concentrations After 100 days

| Cols / Layers | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 2 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 8 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 10 | 7 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 11 | 5 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 6 | 6 | 6 |
| 12 | 11 | 9 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 7 | 8 |
| 13 | 5 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 14 | 15 | 17 | 14 | 23 |
| 14 | 50 | 40 | 40 | 40 | 40 | 41 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 41 | 40 | 40 | 56 |
| 15 | 92 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 87 | 87 | 86 | 83 | 73 | 71 | 95 |
| 16 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 98 | 98 | 98 | 97 | 92 | 89 | 102 |
| 17 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 98 | 100 |
| 18 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 19 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 20 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 21 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Time Step = 50

## Relative Concentrations After 200 days

| Cols / Layers | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 |
| 2 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 8 | 7 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 9 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 |
| 10 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 6 | 6 |
| 11 | 5 | 7 | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 |
| 12 | 19 | 16 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 13 | 13 | 12 | 12 | 12 | 10 | 11 |
| 13 | 14 | 27 | 29 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 27 | 27 | 26 | 26 | 29 | 26 | 35 |
| 14 | 63 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 54 | 54 | 54 | 47 | 52 | 63 |
| 15 | 89 | 86 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 84 | 83 | 80 | 68 | 75 | 92 |
| 16 | 97 | 97 | 97 | 97 | 97 | 97 | 97 | 97 | 97 | 97 | 97 | 97 | 97 | 96 | 94 | 87 | 86 | 100 |
| 17 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 99 | 99 | 97 | 96 | 100 |
| 18 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 99 | 100 |
| 19 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 20 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 21 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Time Step = 100

# Appendix C.VI

## Documentation for the Single Cell Thana Model

# Single Cell Mode Thana Model (SCMTM)

## 1 Introduction

A single cell four layer model was developed for the simulation of groundwater resource potential on an thana basis. The model is derived from the multi-cell model developed for the MPO in 1990.

The model simulates the response of the aquifer system to resource development for a 17 year simulation period, using third monthly time steps. The period of 17 years, which represents the rainfall conditions for the years from 1972/73 to 1988/89, was chosen to reflect the variability in rainfall and consequent potential recharge on the resource potential.

## 2 Modelling Approach

### 2.1 Model Geometry

The aquifer system can be simulated as either 2 or 4 layered, whereby the geometry of the aquifer system for an thana area is defined by the average ground surface elevation and the elevation on the base of the modelled layer. These layers include:

Layer 1 : Upper clays and silts, modelled as a semi-confining layer

Layer 2 : For the two layered situation this represents the combined aquifer whereby it is assumed that the upper finer textured composite aquifer is in complete hydraulic continuity with the medium to coarse textured main aquifer. For the four layered system this layer represents the composite aquifer.

Layer 3 : For the four layered system this represents the aquitard that separates the composite and main aquifers.

Layer 4 : For the four layered system this represents the main aquifer.

### 2.2 Hydrogeological Parameters

For layers 1 and 3 in which vertical flow is simulated the mean vertical hydraulic conductivity values are specified. Together with the saturated thickness they control the hydraulic resistance of these layers.

For the aquifer layers the mean section permeability is specified. Since the model is operated in a single cell mode no lateral transfer of groundwater is simulated. Transmissivity values are however required for the computation of drawdown in wells due to pumping. For the two-layered system two permeability values are used to enable realistic drawdown simulation for different well technologies (STW and DTW).

Specific yield values which exercise the main control over release of water from aquifer storage are specified for the upper 22 m of the aquifer system with values defined for each 1 m interval. The specific yield values were based on the MPO analysis of thana wise depth storage relationships.

## 2.3 Rainfall

Third monthly rainfall totals have been used based on the available records for the period from 1972/73 to 1988/89. These data are available for each thana.

## 2.4 Recharge

The recharge routine is used to compute potential recharge to the aquifer system both from natural sources such as rainfall, flooding and open water bodies, and form irrigation return flow. Potential recharge is equivalent to the potential rate of deep percolation through the base of the active rootzone of dry land crops or through the plough pan for wet land crops. It represents the maximum possible recharge to the aquifer system. In the computation of potential recharge it is assumed that the aquifer system is an infinite storage reservoir without capacity to reject recharge.

Actual recharge is computed in the model by taking into account the constraints of the aquifer system. Actual recharge is always less or equal then potential recharge and can indeed be very small during periods of the monsoon season when groundwater tables are at ground surface. During such period potential recharge is rejected from the system.

The recharge routine simulates potential recharge for third monthly time steps from an analysis of the water balance of the rootzone of different crops.

The methodology of the recharge mechanism is detailed in Annex 1.

## 2.5 Crop Distribution over Land Type Areas

One of the uncertainties associated with the model simulation is the distribution of crops over different land types. During the MPO recharge studies the land type distrubution within an thana was derived from the SODAPS data base.

Land type classification is according to the SODAPS definition based on the depth of normal flooding during the monsoon season. In addition the SODAPS data base specifies permeability ratings namely rapid, moderate and slow. In the recharge model permeability rating is either permeable or impermeable, a distinction mainly based on the capability of impermeable soils to be puddled. The guidelines for determining the permeability ratings used during the MPO recharge studies are as follows :

- Soils categorised in the SODAPS data base as slowly permeable were classified as impermeable, while those with rapid permeability were classified as permeable.

- For those soils described as moderately permeable, the crop suitability was used to classify them as either permeable or impermeable. Soils with a suitability rating of less than 3 for sugarcane were classified as permeable while those with a suitability rating of less than 3 for boro as impermeable.

The land types are classified for modelling purposes into 10 categories as follows:

| Code | Land Type |
|---|---|
| Hp | High Land Permeable |
| Hi | High Land Impermeable |
| MHp | Medium High Land Permeable |
| MHi | Medium High Land Impermeable |
| MLp | Medium Low Land Permeable |
| MLi | Medium Low Land Impermeable |
| L | Low Land |
| B | Bottom Land |
| OW | Open Water |
| HO | Homesteads |

The crop suitability of the diffecrent land types has been adopted from the MPO studies and is defined as follows for irrigated and non irrigated crops:

**Non-irrigated crops**

| Land Type | Crops |
|---|---|
| High Land Permeable | Perennial crops or<br>B.Aus/T.Aus/Jute followed by Wheat/Rabi |
| High Land Impermeable | B.Aus/T.Aman/Jute followed by Rabi |
| Med. High Land Permeable | B.Aus/T.Aus/Jute followed by Wheat/Rabi |

| | |
|---|---|
| Med. High Land Impermeable | B.Aus/T.Aman/Jute followed by Rabi |
| Med. Low Land Permeable | Mixed B.Aus+B.Aman followed by Boro/Wheat/Rabi |
| Med. Low Land Impermeable | Mixed B.Aus+B.Aman followed by Boro/Rabi |
| Low Land | B.Aman followed by Boro/Rabi |
| Bottom Land | Boro |

Irrigated Crops

| Land Type | Crops |
|---|---|
| High Land Permeable | T.Aus followed by Wheat/Rabi |
| High Land Impermeable | T.Aman followed by Boro |
| Med. High Land Permeable | T.Aus followed by Wheat/Rabi |
| Med. High Land Impermeable | T.Aman followed by Boro |
| Med. Low Land Permeable | Boro |
| Med. Low Land Impermeable | Boro |
| Low Land | Boro |
| Bottom Land | Boro |

## 2.6 Flooding

Flood depths are specified for each modelled time step for each land category (ie high land, medium high land etc). Time constraints have limited to specification of an idealised flooding sequence which has been kept constant for the 17 year simulation period.

If flood control is excercised within an thana area the impact on potential recharge and resource potential can simple be evaluated by specifying different flooding depths for the different land categories.

# 3 Assessment of Groundwater Resource Potential

The groundwater resource potential is expressed in terms of percentage of irrigable land that can be irrigated from groundwater during the dry season. The optimum rate of development is controlled by a number of constraints, which are:

- Recharge
  The groundwater resource is utilised as a replenishable resource and thus potential recharge (from both natural sources and from surface water irrigation returns) forms an upper limit on resource development potential.

- Pumping modes
  The suction limit (for STW and DSSTW) and the pump intake setting (for DTW) form constraints to development. In many cases this constraint is the dominant one if STW or DSSTW are selected as the pumping modes. For DTW there is in theory no limit on the pump intake setting although for most existing DTW a intake level of 20 m below ground surface is used.

The assessment of resource potential is one of repeated model simulation. The model would normally first be run under the worst conditions which implies the use of groundwater only for irrigation of high, medium high, medium low and low land without taking account of the beneficial effects of existing surface water irrigation. The cropping pattern would thereby be biased towards boro within the suitability constraints given in Table 2.5. If the resource is capable to sustain the full groundwater development one would have to consider the resulting mode of pumping to achieve the full development level. I full development can thus be achieved by DSSTW there will be no need for further simulation runs.

If the maximum development can only be sustained by DTW the beneficial effects of surface irrigation need to be taken into consideration. If this is done one assumes that bottom land is served by surface water, while the higher lands may be served by groundwater as well as surface water. In the model a ratio is specified of area irrigated from groundwater and total irrigated area. This ratio is specified on a time step basis. The impact of surface water irrigation on the groundwater resource potential can thus be analysed and it is conceivable that under these conditions a suction mode pumping technology is possible.

If potential recharge is shown to be a constraint to groundwater development than the area irrigated from groundwater will have to be reduced. The reduced area could then either not be irrigated or be irrigated from a surface water resource.

If the aquifer system consists of four layer it is assumed that STW and DSSTW abstract from the upper aquifer while DTW have their screen set in the lower aquifer. In this case the user would specify the proportion of total groundwater abstraction derived from the lower (main) aquifer. This set up of the model allows for a realistic simulation of conditions in areas where STW and DSSTW are still operation despite the fact that piezometric levels in the lower aquifer have drop below the suction limit of the STW/DSSTW.

An example of a simulation sequence is given in Annex 3 for Brahamnbaria thana.

## 4 Model Output

The output from the model is directed to a .PRN file which can be imported into a Lotus spreadsheet for additional manipulation and for preparation of graphical output. The output is described in detail in Appendix 1 and includes in suummary the following for each modelled time step:

- Pumping levels for force mode and suction mode wells (generally 2 cusec DTW and 0.5 cusec STW/DSSTW).
- Piezometric levels in the two aquifer layers.
- Water table levels for 6 relief phases (H, MH, ML, L, B and OW).
- Gross abstraction from groundwater.
- Actual recharge (sum of natural recharge and irrigation return flow).
- Storage changes in the aquifer and in the upper clay/silt layer.
- Total gross application of irrigation water (sum of groundwater and surface water supply).
- Return flow from irrigation.
- Gross rainfall.

All flow components are presented in mm/d/unit gross area.

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ANNEX 1

## Methodology of Recharge Simulation

### 1 Methodology

In the model a distinction is made between infiltration and deep percolation rates. The infiltration rate is defined as the rate of flow through the soil surface. The deep percolation is the rate of downward flow through the base of the active rootzone or through the ploughpan.

The model assumes that all recharge is vertical. This includes the interaction between surface water (rivers, bheels, etc.) which given the basic assumption of a very deep groundwater table is valid. The model does thus not simulate the lateral transfer between rivers and the aquifer.

A large number of parameters affect the potential recharge. They may be categorised in major groups as summarised below :

- Physical parameters
  - land type distribution;
  - soil characteristics within land type areas;
  - local relief characteristics.

- Hydrological parameters
  - rainfall (totals, distribution, frequency);
  - relationship between effective and gross rainfall;
  - surface water retention capacity for different land types;
  - surface runoff characteristics;
  - extent, duration and depth of deep flooding;
  - reference crop evapotranspiration.

- Parameters related to agricultural practices
  - crop coefficients;
  - cropping calendar;
  - cropping patterns related to soil and land types;
  - rooting depth of crops, or depth to ploughpan;
  - ratio of cultivable to gross area;
  - crop statistics.

Deep percolation is calculated from the water balance of the rootzone and is assumed only to take place if the moisture content in the rootzone is above the value at field capacity. This simply assumes the build up of perched conditions at the base of the rootzone and in this case the deep percolation is equal to the gravity drainage capacity of the plough pan or the subsoil. If flood levels build up, then the rate of deep percolation increases in proportion to the height of the standing water at the soil surface. Summarised the deep percolation (or potential recharge) follows from :

| | |
|---|---|
| If soil moisture below field capacity | : DP = 0 |
| If soil moisture above field capacity but no deep flooding | : DP = $K_v$ |
| If deep flooding | : DP = $(DF+1)*K_v$ |

| | | | |
|---|---|---|---|
| where | DP | = | deep percolation |
| | $K_v$ | = | vertical permeabilty of the subsoil or ploughpan |
| | DF | = | flood level relative to soil surface |

## 2 Data Requirements

### Introduction

The data requirements for the recharge model are summarised as follows :

(a) Land type distribution
(b) Soil distribution over land type areas
(c) Crop statistics
(d) Cropping calendar
(e) Reference crop evapotranspiration
(f) Crop coefficients
(g) Effective rooting depths
(h) Rainfall
(i) Surface water retention and flooding
(j) Infiltration and deep percolation rates
(k) Soil moisture characteristics
(l) Effective rainfall and surface runoff
(m) Initial soil moisture conditions

Most data wer derived from the MPO data and only required some restructuring into appropriate data files. These structure of these data files is given in Appendix 1.

Land Type Distribution

Land type classification is according to the SODAPS definition, which takes as the main criterion for classification the depth of flooding during the monsoon season. The land types are classified for the recharge model into 10 major categories as shown in Table 2.1

The permeability rating, permeable or impermeable, is different from the one used in the SODAPS data base. SODAPS uses three permeability ratings namely rapid, moderate and slow. The guidelines for determining the permeability ratings used in the land type classification are as follows :

- Soils categorised in the SODAPS data base as slowly permeable were classified as impermeable, while those with rapid permeability were classified as permeable.

- For those soils described as moderately permeable, the crop suitability was used to classify them as either permeable or impermeable. Soils with a suitability rating of less than 3 for sugarcane were classified as permeable while those with a suitability rating of less than 3 for boro as impermeable.

It should be noted that permeability ratings relate to sub-soil characteristics.

The land type distribution for the thanas within the project area are given in Table 2.2.

Table 2.1

LAND TYPE CLASSIFICATION

| Code | Land Type | |
|---|---|---|
| 1 | High Land Permeable | HP |
| 2 | High Land Impermeable | HI |
| 3 | Medium High Land Permeable | MHP |
| 4 | Medium High Land Impermeable | MHI |
| 5 | Medium Low Land Permeable | MLP |
| 6 | Medium Low Land Impermeable | MLI |
| 7 | Low Land | L |
| 8 | Bottom Land | B |
| 9 | Open Water | OW |
| 10 | Homesteads | HO |

Soil Distribution over Land Type Areas

A variety of soil types may exist for each land type. In the model only the three most dominant soil types within the

land type area are taken into consideration. Soil types used in the model are shown in Table 2.3. Their physical characteristics were based on Rijtema (1969).

Table 2.3

SOIL TYPES USED IN THE RECHARGE MODEL

| Code | Type | Abreviation |
|---|---|---|
| 1 | Fine Sandy Loam | FSL |
| 2 | Silt Loam | SiL |
| 3 | Loam | L |
| 4 | Silty Clay Loam | SiCL |
| 5 | Clay Loam | CL |
| 6 | Basin Clay | BC |
| 7 | Silty Clay | SiC |
| 8 | Sandy Clay Loam | SCL |

**Table 2.2**

**Land Type Distribution in Project Area**

Land Type Distribution in South East Region

| Thana Code | Name | Area km² | Land Types (%) Hp | Hi | MHp | MHi | MLp | MLi | L | B | OW | HO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | AKHAURA | 93.0 | 14.74 | 3.55 | 9.72 | 2.41 | 8.03 | 14.70 | 21.01 | 12.65 | 5.88 | 7.31 |
| 14 | ASHUGANJ | 119.0 | | | | | | | | | | |
| 42 | BANCHARAMPUR | 207.0 | | | | | | | | | | |
| 53 | BARURA | 240.0 | 11.10 | 0.00 | 24.36 | 9.10 | 30.05 | 16.94 | 0.13 | 0.00 | 8.32 | 0.00 |
| 58 | BEGUMGANJ | 409.0 | 21.51 | 0.00 | 9.72 | 0.24 | 32.46 | 29.97 | 1.10 | 0.00 | 5.00 | 0.00 |
| 87 | BRAHMANBARIA | 416.0 | 14.96 | 1.69 | 14.41 | 0.81 | 16.43 | 5.20 | 17.14 | 21.93 | 7.43 | 0.00 |
| 88 | BRAHMANPARA | 119.0 | 0.37 | 0.18 | 10.80 | 5.80 | 36.99 | 26.02 | 5.27 | 0.00 | 6.39 | 8.18 |
| 90 | BURICHANG | 181.0 | 2.84 | 2.00 | 14.50 | 34.43 | 4.76 | 21.45 | 1.36 | 0.00 | 9.98 | 8.68 |

Table 2.6 (Continued)

| Thana Code | Name | Area | Land Types (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $km^2$ | Hp | Hi | MHp | MHi | MLp | MLi | L | B | OW | HO |
| 94 | CHANDINA | 202.0 | 0.12 | 0.00 | 19.43 | 12.74 | 2.81 | 6.73 | 40.69 | 0.00 | 8.37 | 9.11 |
| 96 | CHANDPUR | 287.0 | 6.63 | 0.00 | 15.38 | 0.11 | 22.86 | 2.78 | 0.54 | 0.00 | 28.47 | 23.23 |
| 102 | CHATKHIL | 134.0 | 24.70 | 0.00 | 22.50 | 9.11 | 12.07 | 18.84 | 7.78 | 0.00 | 5.00 | 0.00 |
| 104 | CHAGALNAIYA | 157.0 | | | | | | | | | | |
| 111 | CHOUDDAGRAM | 271.0 | 12.86 | 2.06 | 41.89 | 19.16 | 4.33 | 9.06 | 0.65 | 0.00 | 9.99 | 0.00 |
| 116 | COMPANIGANJ | 189.0 | 0.00 | 0.00 | 15.95 | 24.62 | 0.93 | 1.50 | 0.00 | 0.00 | 46.75 | 10.25 |
| 120 | DAGANBHUIYA | 132.0 | 17.16 | 0.00 | 39.52 | 2.15 | 13.07 | 19.60 | 2.70 | 0.00 | 5.81 | 0.00 |
| 125 | DOUDKANDI | 375.0 | 0.00 | 0.00 | 0.00 | 0.00 | 4.75 | 0.00 | 56.96 | 22.20 | 10.13 | 5.96 |
| 130 | DEBIDWAR | 235.0 | 0.00 | 0.00 | 28.27 | 14.56 | 18.07 | 11.50 | 10.02 | 0.00 | 8.60 | 8.98 |
| 155 | FARIDGANJ | 235.0 | 20.83 | 0.00 | 37.48 | 5.74 | 3.96 | 7.16 | 2.07 | 0.00 | 5.39 | 17.37 |
| 161 | FENI | 221.0 | 21.95 | 0.00 | 41.46 | 19.51 | 4.30 | 2.99 | 2.86 | 0.00 | 6.93 | 0.00 |
| 166 | FULGAZI | 108.0 | 33.00 | 0.30 | 46.85 | 15.73 | 0.00 | 2.14 | 0.00 | 0.00 | 1.98 | 0.00 |
| 194 | HAIMCHAR | 186.0 | 4.99 | 0.00 | 10.02 | 3.53 | 19.70 | 4.32 | 0.01 | 0.00 | 43.85 | 13.58 |
| 195 | HAJIGANJ | 157.0 | 25.04 | 0.00 | 1.40 | 0.00 | 26.18 | 31.33 | 7.97 | 0.00 | 8.08 | 0.00 |
| 204 | HOMNA | 178.0 | 0.00 | 0.00 | 0.00 | 0.00 | 4.17 | 0.00 | 43.43 | 28.78 | 19.55 | 4.07 |
| 225 | KACHUA | 238.0 | 0.03 | 0.00 | 0.99 | 0.00 | 44.14 | 7.10 | 11.96 | 0.00 | 20.26 | 15.52 |
| 249 | KASBA | 207.0 | 16.93 | 0.87 | 24.86 | 2.07 | 24.95 | 4.21 | 8.54 | 3.60 | 7.42 | 6.55 |
| 271 | KOTWALI | 277.0 | 12.27 | 3.33 | 11.41 | 34.94 | 0.75 | 18.48 | 0.00 | 0.00 | 6.25 | 12.57 |
| 287 | LAKSHAM | 427.0 | 10.04 | 0.00 | 28.44 | 2.99 | 29.07 | 12.59 | 8.24 | 0.00 | 8.63 | 0.00 |
| 288 | LAKSHMIPUR | 515.0 | 20.97 | 0.94 | 21.86 | 24.45 | 14.43 | 5.73 | 0.00 | 0.00 | 11.62 | 0.00 |
| 312 | MATLAB | 409.0 | 0.03 | 0.00 | 0.99 | 0.00 | 44.14 | 7.10 | 11.96 | 0.00 | 20.26 | 15.52 |
| 343 | MURADNAGAR | 341.0 | 0.00 | 0.00 | 14.69 | 5.73 | 16.86 | 8.48 | 37.20 | 1.69 | 7.29 | 8.06 |
| 345 | NABINAGAR | 352.0 | 6.27 | 0.00 | 21.44 | 0.22 | 37.39 | 1.82 | 8.72 | 10.48 | 13.66 | 0.00 |
| 356 | NANGALKOT | 235.0 | | | | | | | | | | |
| 362 | NASIRNAGAR | 313.0 | 0.00 | 0.00 | 0.54 | 0.00 | 33.09 | 13.66 | 15.71 | 18.65 | 7.46 | 10.89 |
| 388 | PARSURAM | 72.0 | 38.95 | 0.61 | 39.93 | 12.08 | 0.00 | 0.00 | 0.00 | 0.00 | 1.32 | 7.11 |
| 405 | RAIPUR | 202.0 | 11.15 | 0.00 | 31.79 | 16.05 | 3.99 | 1.12 | 0.00 | 0.00 | 17.87 | 18.03 |
| 411 | RAMGANJ | 170.0 | | | | | | | | | | |
| 413 | RAMGATI | 650.0 | 0.00 | 0.00 | 29.50 | 23.81 | 2.50 | 1.01 | 0.00 | 0.00 | 32.13 | 11.05 |
| 437 | SARAIL | 212.0 | 0.00 | 0.00 | 16.25 | 0.00 | 17.82 | 6.69 | 27.85 | 14.94 | 7.60 | 8.85 |
| 445 | SENBAG | 160.0 | 20.03 | 0.00 | 34.45 | 1.64 | 15.53 | 23.64 | 0.46 | 0.00 | 4.25 | 0.00 |
| 447 | SHAHARASTI | 186.0 | 24.62 | 0.00 | 9.10 | 3.63 | 15.90 | 27.11 | 13.94 | 0.00 | 5.70 | 0.00 |
| 459 | SHUDHARAM | 828.0 | 6.03 | 13.14 | 20.52 | 32.49 | 4.51 | 2.85 | 0.00 | 0.00 | 20.46 | 0.00 |
| 465 | SONAGAZI | 259.0 | 1.10 | 0.00 | 38.14 | 13.10 | 5.93 | 1.46 | 0.00 | 0.00 | 28.53 | 11.74 |

Crop Distribution over Land Type Areas

Crop statistics are available on an upazilla basis from the BBS data books. The Agronomy Section of MPO have computerised this data from 1974/75 for 16 major crops or crop groups. For the recharge model the number of crops was reduced to 10 major non-irrigated crops or crop groups plus forest and grass/wild vegetation plus four irrigated crops. The correlation between the crops is given in Table 2.4.

The statistics data do not indicate the distribution of crops over the various land type areas. For the recharge calculations the link between crop type and land type is, however, of major significance. The correlation between crops and land types is based on Table 2.5. In the model adjustments are made if necessary.

Table 2.4

CROP TYPES

| Agronomy Section | | Recharge Model | |
|---|---|---|---|
| | | | Non-Irrigated |
| 1 | B.Aus | 1 | B.Aus |
| 2 | T.Aus | 2 | T.aus |
| 3 | B.Aman | 4 | B.Aman |
| 4 | Local T.Aman | 3 | T.Aman |
| 5 | HYV T.Aman | 3 | T.Aman |
| 6 | Local Boro | 5 | Boro |
| 7 | HYV Boro | 5 | Boro |
| 8 | Wheat | 7 | Wheat |
| 9 | Potato | 7 | Wheat |
| 10 | Jute | 6 | Jute |
| 11 | Sugarcane | 9 | Sugarcane |
| 12 | Pulses | 8 | Rabi |
| 13 | Oil Seeds | 8 | Rabi |
| 14 | Spices | 8 | Rabi |
| 15 | Other Crops | 8 | Rabi |
| 16 | Orchards | 10 | Orchards |
| | | 11 | Forest |
| | | 12 | Grass/wild vegetation |
| | | | Irrigated |
| | | 13 | Wheat/Rabi |
| | | 14 | Boro |
| | | 15 | T.Aus |
| | | 16 | T.Aman |

Cropping Calendar

Date of first planting, harvesting dates and length of growing season vary slightly throughout the country and planting and harvesting may stretch out over quite significant periods. For ease of calculation in the model it is assumed that planting and harvesting periods for rice and jute are 40 days, and for wheat and rabi 30 days. It is further important that the growing seasons of successive crops do not overlap, since this may cause the occurrance of cropped areas in excess of available cultivable area.

Table 2.5

LAND TYPE VERSUS CROP TYPE

| Land Type | Crops (non-irrigated) |
|---|---|
| High Land Permeable | Orchards/Forest/Sugarcane<br>B.Aus/T.Aus/Jute, Wheat/Rabi |
| High Land Impermeable | B.Aus/T.Aman/Jute, Rabi |
| Med. High Land Permeable | B.Aus/T.Aus/Jute, Wheat/Rabi |
| Med. High Land Impermeable | B.Aus/T.Aman/Jute, Rabi/Boro |
| Med. Low Land Permeable | Mixed B.Aus + B.Aman, Wheat/Rabi/Boro |
| Med. Low Land Impermeable | Mixed B.Aus + B.Aman, Rabi/Boro |
| Low Land | B.Aman, Rabi/Boro |
| Bottom Land | Boro |

| Land Type | Crops (irrigated) |
|---|---|
| High Land Permeable | Wheat/Rabi, T.Aus |
| High Land Impermeable | Boro, T.Aman |
| Med. High Land Permeable | Wheat/Rabi, T.Aus |
| Med. High Land Impermeable | Boro, T.Aman |
| Med. Low Land Permeable | Boro |
| Med. Low Land Impermeable | Boro |
| Low Land | Boro |
| Bottom Land | Boro |

T.Aman may shift to medium low and low land if this becomes flood protected.

Reference Crop Evapotranspiration

Reference crop evapotranspiration is available from a number of meteorological stations throughout the country. Monthly data can be reworked into shorter periods with reasonable confidence using curve fitting and interpolation routines.

Crop Coefficients

Crop coefficients were based on values derived during the first phase of MPO and are shown in Table 2.6. For broadcast rice the consideration is given to possible saturated soil conditions during the early stages of the crop. Under such conditions a coefficient of 1.1 is used in the recharge model.

Table 2.6

CROP COEFFICIENTS

Values given are for third monthly periods from 1st March

Note : Values given should be in accordance with the cropping calendar

Non-Irrigated Crops

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B.aus | | | | | | | | | | | |
| 0.00 | 0.00 | 0.45 | 0.51 | 0.59 | 0.68 | 0.83 | 0.96 | 1.05 | 1.09 | 1.09 | 1.05 |
| 0.99 | 0.95 | 0.90 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T.aus | | | | | | | | | | | |
| 0.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.09 | 1.05 |
| 0.99 | 0.95 | 0.90 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| T.aman | | | | | | | | | | | |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |
| 1.09 | 1.05 | 0.99 | 0.95 | 0.90 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| B.aman | | | | | | | | | | | |
| 0.00 | 0.00 | 0.45 | 0.51 | 0.59 | 0.68 | 0.83 | 0.96 | 1.05 | 1.09 | 1.10 | 1.10 |
| 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.05 | 0.99 | 0.95 | 0.90 |
| 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Boro | | | | | | | | | | | |
| 1.19 | 1.24 | 1.26 | 1.22 | 1.11 | 1.06 | 0.98 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.11 | 1.14 |

Table 2.6 (continued)

Jute

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.42 | 0.45 | 0.49 | 0.57 | 0.70 | 0.85 |
| 0.98 | 1.00 | 1.11 | 1.15 | 1.11 | 1.02 | 0.98 | 0.90 | 0.80 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Wheat

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.80 | 0.69 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.45 | 0.51 | 0.59 | 0.75 | 0.92 | 1.05 | 1.12 | 1.13 | 1.10 | 1.01 |

Rabi

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.01 | 0.80 | 0.69 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.45 | 0.51 | 0.59 | 0.75 | 0.92 | 1.05 | 1.12 | 1.13 | 1.10 |

Sugar cane

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.97 | 1.00 | 1.04 | 1.06 | 1.08 | 1.10 | 1.12 | 1.13 | 1.14 | 1.14 | 1.15 | 1.15 |
| 1.15 | 1.15 | 1.14 | 1.13 | 1.12 | 1.09 | 1.06 | 1.02 | 0.98 | 0.93 | 0.88 | 0.84 |
| 0.81 | 0.79 | 0.77 | 0.75 | 0.74 | 0.74 | 0.74 | 0.76 | 0.79 | 0.83 | 0.87 | 0.92 |

Fruit trees and Forest

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |

Non-cultivable waste

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.30 | 0.40 | 0.40 | 0.40 | 0.50 | 0.60 | 0.60 |
| 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.50 | 0.50 | 0.40 | 0.30 |
| 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |

Irrigated Crops

Wheat

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.80 | 0.69 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.45 | 0.51 | 0.59 | 0.75 | 0.92 | 1.05 | 1.12 | 1.13 | 1.10 | 1.01 |

Boro

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.11 | 1.14 | 1.19 | 1.24 | 1.26 | 1.22 | 1.11 | 1.06 | 0.98 | 0.85 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |

T.aus

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.09 | 1.05 |
| 0.99 | 0.95 | 0.90 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

T.aman

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |
| 1.09 | 1.05 | 0.99 | 0.95 | 0.90 | 0.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Effective Rooting Depth

The effective rooting depth is for most crops dependent on the subsoil conditions and may thus be greater or smaller than general values such as presented in FAO Publication 24. A tight clay at shallow depth would restrict root penetration to a major extent, while the existance of a plough pan will have a similar effect. The range of values that may be adopted in the model are shown in Table 2.7. Adjustments may be required depending on local conditions.

Table 2.7

ROOTING DEPTHS

| Crop | Rooting Depth (m) |
|---|---|
| Rice | 0.3 - 0.6 |
| Jute | 0.4 - 0.8 |
| Wheat | 0.6 - 1.0 |
| Rabi | 0.4 - 1.0 |
| Sugarcane | 1.0 - 2.0 |
| Trees | 2.0 - 3.0 |
| Wild vegetation | 0.5 - 1.0 |

**Surface Water Retention and Flooding**

The land is classified into different land types according to the depth of normal flooding during the height of the monsoon season. The relationship between land type and flood depth is given in Table 2.8.

Table 2.8

LAND TYPE VERSUS FLOOD DEPTH

| Land Type | Flood Depth |
|---|---|
| High Land | not flooded or less than 0.3 m |
| Medium High Land | 0.3 to 0.9 m |
| Medium Low Land | 0.9 to 1.8 m |
| Low Land | 1.8 to 3.0 m |
| Bottom Land | greater than 3.0 m |

The depth of flooding may vary throughout the monsoon season, while its duration will depend on the land type and other factors. In the model flood depths and start and end of the deep flooding period have to be specified.

For land not subject to flooding, water can be held in surface storage between field 'bunds'. This also applies for periods outside the flood season for land that is subject to flooding. In the model hypothetical 'bund' heights for the different land types are adopted for 'wet' (rice and jute) and 'dry' (wheat, rabi etc) crops which do not necessarily reflect actual bund height in the field. Water can thus be held in surface storage up to a maximum level determined by the specified 'bund' height.

### Infiltration and Deep Percolation Rates

Data based on field experiments conducted by the Soils Survey Department give infiltration rates for dry and moist soil conditions. The range of values for seven soil types are given in Table 2.9.

Table 2.9

INFILTRATION RATES

| Soil Texture | Infiltration Rates (m/d)* | | |
|---|---|---|---|
| | | Dry | Moist |
| Fine sandy loam | 0.48 - 2.40 | 0.048 - 0.249 | |
| Silt Loam | 0.48 - 2.40 | 0.048 - 0.192 | |
| Loam | 0.48 - 2.40 | 0.396 | |
| Silty Clay Loam | 0.48 - 2.40+ | 0.048 - 0.120 | |
| Clay Loam | 0.48 - 2.40+ | 0.084 | |
| Silty Clay | 1.80+ | 0.048 - 0.072 | |
| Basin Clay | 0.84 - 1.92+ | 0.024 - 0.072 | |

* Increased rate due to soil cracks

\+ Values obtained from MPO Soils Section

Values adopted in the recharge model are 0.025 m/d for silty clay and basin clay, and 0.05 m/d for the other soils.

Deep percolation rates are often an order of magnitude smaller than the infiltration rates. The likely range for eight soil types and for 'wet' and 'dry' conditions were based on simulation of potential recharge by the MPO and are given in Table 2.10.

Table 2.10

DEEP PERCOLATION RATES

| Soil Texture | Minimum Deep Percolation Rates (mm/d) | |
|---|---|---|
| | 'Wet' | 'Dry' |
| Fine sandy loam | 5-15 | 25 |
| Silt loam | 3-9 | 10 |
| Loam | 5-15 | 15 |
| Silty clay loam | 3-9 | 15 |
| Clay loam | 2-6 | 5 |
| Basin clay | 1-3 | 5 |
| Silty clay | 1-3 | 5 |
| Sandy clay loam | 3-9 | 15 |

**Soil Moisture Characteristics**

Soil moisture characteristics are based on Rijtema (1970). The soil moisture contents at full saturation, field capacity and wilting point for the eight soil types are given in Table 2.11. Field capacity is defined as the condition where moisture tension is 100 cm (pF=2.0) and approximates the moisture content that can be held in the soil against gravity forces. Wilting point is defined as the condition where moisture tension is 16,000 cm (pF=4.2) and represents the condition where plants loose their ability to extract moisture from the rootzone.

**Table 2.11**

**SOIL MOISTURE CHARACTERISTICS**

| Soil Texture | Moisture Content (%) | | |
|---|---|---|---|
| | Full Saturation | Field Capacity | Wilting Point |
| Fine sandy loam | 50.4 | 42.3 | 8.7 |
| Silt loam | 50.9 | 46.1 | 9.2 |
| Loam | 50.3 | 42.0 | 9.8 |
| Silty clay loam | 47.5 | 37.2 | 18.5 |
| Clay loam | 44.5 | 41.1 | 25.5 |
| Basin clay | 54.0 | 51.9 | 32.1 |
| Silty clay | 50.7 | 46.3 | 25.7 |
| Sandy clay loam | 43.2 | 33.8 | 18.0 |

Effective Rainfall and Surface Runoff

Effective rainfall is calculated for 'wet' and 'dry' land areas for each land type according to the following equations :

If mean daily rainfall is less than 1 mm/d for the considered time period :

$$ER = 0$$

Otherwise :

$$ER = PR * (R - 1)$$

where ER - effective rainfall in mm/d
R - actual rainfall in mm/d
PR - factor depending on land type and land use ('wet' and 'dry') (PR <= 1)

Values for PR were based initially on findings from previous modelling studies and the likely range is shown in Table 2.12.

**Table 2.12**

**EFFECTIVE RAINFALL FACTORS**

| Land Type | | PR | |
|---|---|---|---|
| | | 'Wet' | 'Dry' |
| High Land | P | 0.7 - 0.9 | 0.7 - 0.9 |
| High Land | I | 0.7 - 0.9 | 0.7 - 0.9 |
| Med. High Land | P | 0.7 - 0.9 | 0.7 - 0.9 |
| Med. High Land | I | 0.7 - 0.9 | 0.7 - 0.9 |
| Med. Low Land | P | 0.8 - 1.0 | 0.8 - 1.0 |
| Med. Low Land | I | 0.8 - 1.0 | 0.8 - 1.0 |
| Low Land | | 0.8 - 1.0 | 0.8 - 1.0 |
| Bottom Land | | 0.8 - 1.0 | 0.8 - 1.0 |

Surface runoff due to excess rainfall is calculated as the difference between actual and effective rainfall minus interception (1 mm/d).

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ANNEX 2

## 1 Structure of the Model

The structure of the model and an associated data preparation data checking program is shown in Figure 1.1. The functions of the programs and associated subroutines are summarised as follows:

- Program DATAPREP

  This program reworks basic data into a binary master file, which is used as input file to the model. Two subroutines are associated with this program. Subroutine LTCMOD is used to distribute crops over land type areas. Subroutine INFMOD is used to convert infiltration, deep percolation and soil moisture characteristics from a soil type basis to a land type basis.

- Program CHECK

  This program is used to create a printer ready copy of the data generated by program DATAPREP.

- Program SCMTM

  This program performs the numerical calculations required for the simulation of the groundwater system. 21 subroutines are linked with the program which are briefly described in the following.

- Subroutine RECHMOD

  Recharge to groundwater and irrigation requirements are computed in this subroutine.

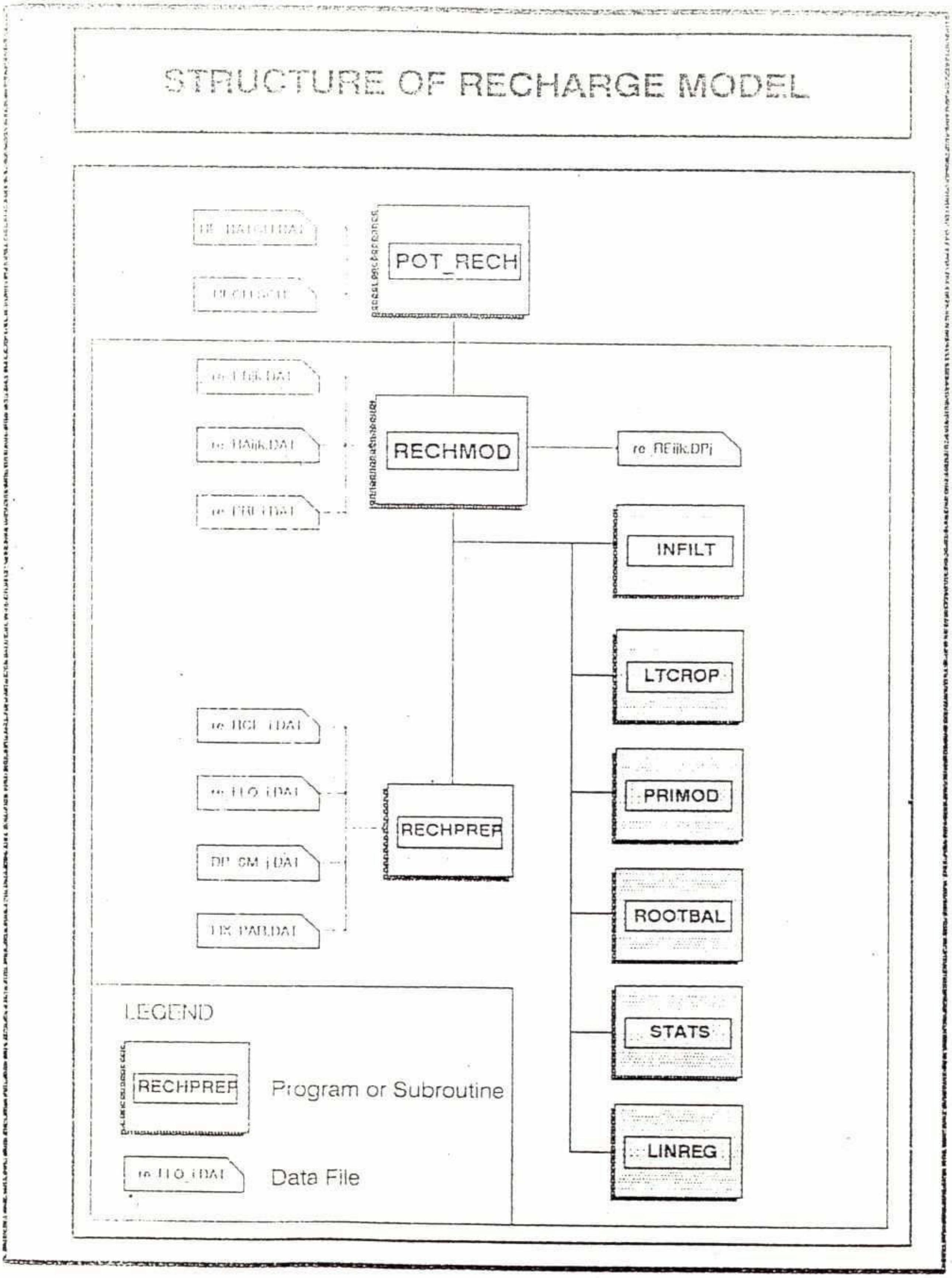
- Subroutine STORAGE

  In this subroutine the storage changes in the aquifer and the semi-confining layer are computed.

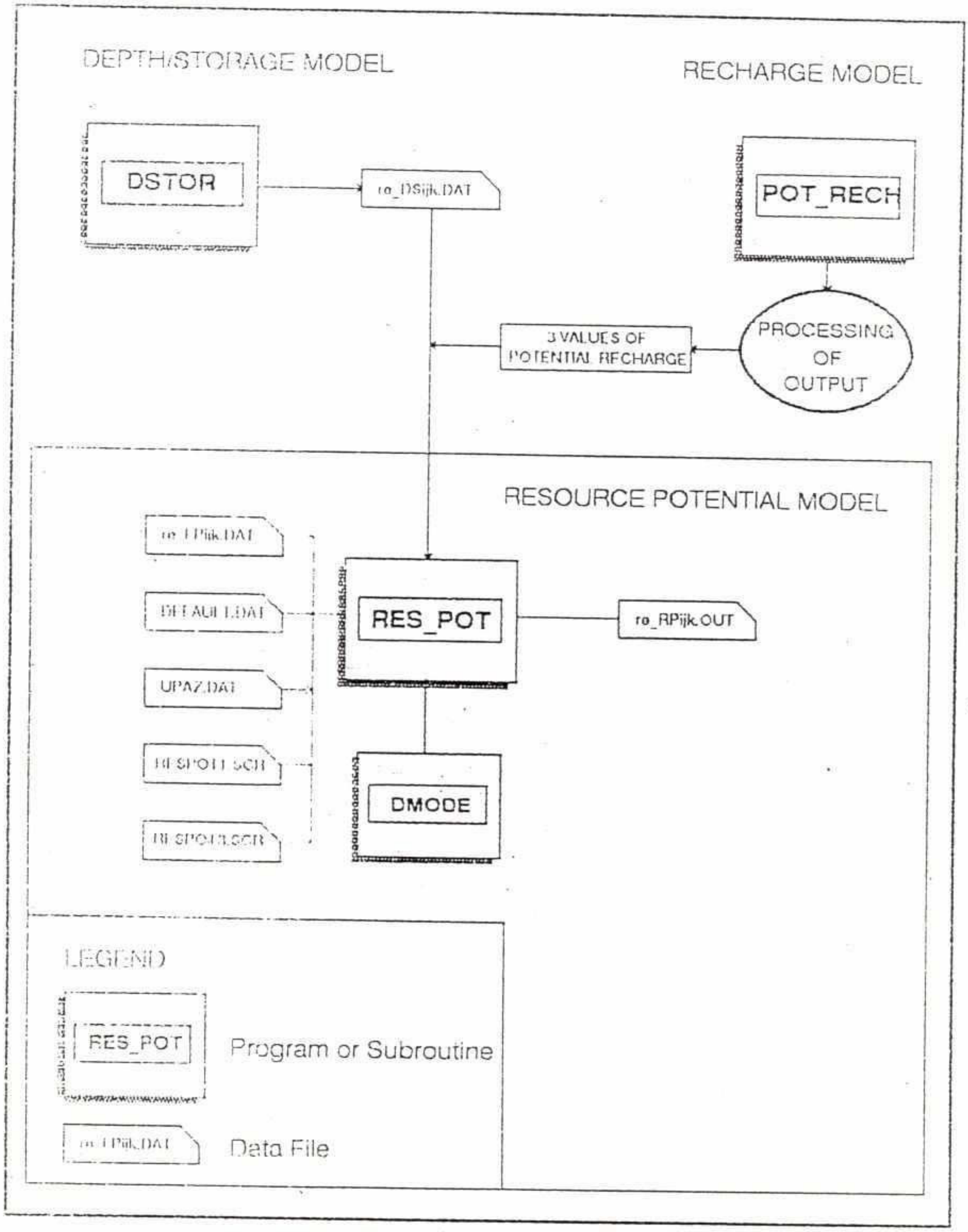
- Subroutine HDCORRM

  In this subroutine head corrections are computed for the aquifer and for the 6 land categories of the semi-confining layer.

Figure 1.1


STRUCTURE OF RECHARGE MODEL
POT_RECH
RECHMOD
re_REiik.DPi
INFILT
LTCROP
PRIMOD
ROOTBAL
STATS
LINREG
RECHPREP
LEGEND
RECHPREP
Program or Subroutine
Data File

# STRUCTURE OF RESOURCE POTENTIAL MODEL



- Subroutine INPUT

  Model input data are entered in this subroutine.

- Subroutine PRIMOD

  In this subroutine the actual crop coverage for the current time step is computed for each land type.

- Subroutine FLOOD

  Recharge due to deep flooding conditions is computed in this subroutine.

- Subroutine RBALMOD

  In this subroutine the moisture balance of the rootzone of non-irrigated crops computed for conditions where the water table is positioned below the base of the rootzone.

- Subroutine CAPILM

  Capillary flux from the water table to the rootzone is computed in this subroutine.

- Subroutines WHEAT, BORO, AUS and AMAN

  In these subroutines the moisture balance and the irrigation requirements are computed for the four irrigated crops.

- Subroutines SUB1 to SUB6 and SUB8

  These subroutines are linked to the subroutines that compute the moisture balance for irrigated crops.

- Subroutine SUB7

  In this subroutine soil moisture and surface storage are redistributed.

## 2 File Specification

The file structure of the model may be summarised as follows :

- Files which need to be specified for each thana

  These files include :

(a) File re_GHijk.DAT

This file contains the data defining the aquifer geometry, its hydrogeological parameters and the soil type distribution over land type areas. The file also contains infiltration, deep percolation and soil moisture characteristics for the 8 soil types incorporated in the model.

(b) File re_LTijk.DAT

This file contains the data defining the land type distribution within each thana, information regarding flood protection of certain land types, and the cropped areas for each cropping season of the simulation period.

(c) File re_RAijk.DAT

This file contains the third monthly rainfall totals for the simulation period.

(d) File re_FLijk.DAT

This file contains the depth of deep flooding for each third monthly period for each land type. The flooding characteristics represent the long term mean for the simulation period.

(e) File re_ICijk.DAT

This file contains intitial values of aquifer piezometry and water table levels and data defining non-agricultural groundwater abstraction.

(f) File re_IPijk.DAT

This file contains data defining effective rainfall factors, bund heights, rooting depths and irrigation management parameters.

The file name convention is such that the region code and the thana number can be recognised from the file name. 're' refers to the region code (NE, NW, SE or SW) while ijk refers to the thana number (eg 054).

- Files which need to be specified for the region

These files include :

(g) File re_RCE.DAT

This file contains the mean reference crop evapo- transpiration values for third monthly periods and the crop coefficients for 12 non-irrigated crops and 4 irrigated crops.

(h) File re_PRI.DAT

This file contains the cropping calendar for the 12 non-irrigated and 4 irrigated crops in the form of proportion crop coverage relative to maximum crop coverage for each simulated time step.

The file names include the region code 're'.

- Screen file

(i) File INPUT.SCR

This file contains the start-up template for a model simulation run.

- Other files

(j) File PARAM.DAT

This file contains the model run control parameters.

(k) File FLUX.BIN

This binary file is generated by program FLUXDAT and contains the capillary flux characteristics for the 8 soil types given in Table 2.3.

- Output file

(j) File re_MOijk.PRN

This file contains the simulated model output for each third monthly time step. The file can be imported into Lotus 123 for further processing.

Examples of input and output files are shown in Appendix A.

## 3 Program Operation and Directory Structure

Executable programs are stored in (sub)-directory EXE, while data files which are general or specific to the region are stored in (sub)-directory DATA. Files which are related to individual thanas are stored in separate sub-directories of directory DATA. The thana sub-directory names are identical to the MPO thana code (eg 087 for Brahmanbaria). The programs are operated from directory DATA by specifying the program name.

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## Appendix C.VII

## Theoretical Analysis of Deep and Shallow Tubewell Operation under Comparable Conditions

# Theoretical Analysis of Deep and Shallow Tubewell Operation under Comparable Conditions

## 1 Introduction

Despite a considerable literature on the economics of tubewell irrigation in Bangladesh, few studies have combined the technical and economic factors determining the choice between deep tubewells (DTW) and shallow tubewells (STWs). The purpose of the paper to clarify the fundamental linkage between the technical and economic factors, and is not concerned with the general incentive to irrigate, farmer organisation, credit and financing, or cropping patterns; such matters have been described elsewhere (e,g Sadeque and Hakim). The analysis assumes that for a given location the decision to irrigate a *boro* rice crop has been taken, and that groundwater is the only available source of water.

It is the premise of this paper that previous analyses have produced distorted interpretations of the optimum economic choice of technology through the use of average costs and benefits derived from dissimilar geographical areas, and because they have not given proper attention to the different operating characteristics of the pumping units used. Previous analyses have also been distorted by the different objectives of public sector and private sector irrigation wells. Many published STW costs were measured in very easily developed aquifers such as in North Bengal or the Jamuna Floodplain, whereas most deep tubewell costs are from relatively difficult areas such as the Madhupur and Barind Tracts. It is not the intention of this work to argue the case of whether STW or DTW is better, for both have their roles, rather the intention is to identify the proper (economic) point of transition.

The key environmental factors influencing the choice between DTW and STW are:

- depth of the aquifer
- permeability of the aquifer
- the depth of the water table
- occurrence of natural gas

of which only the first three are considered here. Natural gas discharges may render STWs inoperable in areas that would otherwise appear highly favourable (e.g. parts of Comilla District); it is a problem that simply rules out STW operation and is therefore not relevant to this analysis. The other factors, however, directly influence the cost of irrigation. Other environmental factors, such as soil type and flooding phase, tend to influence the decision of whether or not to irrigate rather than the choice of technology. Compared to deep tubewell irrigation, STW irrigation is a low capital cost - high operating cost - short working life option. Thus STW irrigation is to be preferred where the water table is near the ground surface and the aquifer is most permeable, which combine to give low pumping costs, and where the aquifer is shallow and hence the well is cheaper to construct. It is quite likely that in many cases farmers may prefer STWs because of the difficulty of raising investment capital in rural society, however, for water resources planning purposes it is desirable to determine the environmental parameters that mark the economic transition.

Planning policies towards shallow tubewells have been subject to major changes during the 1980's. In the early eighties STWs were prohibited in many thanas because they were held to interfere with the efficient development of DTW irrigation, which was provided on a highly subsidised basis through BADC in all areas outside the coastal region. These restrictions were later withdrawn, and replaced with attempts to restrict the supply of subsidised DTWs to more difficult aquifer areas. At present there is tendency for policies to swing to the other extreme, with proposals for prohibiting DTWs from all areas where STWs can operate.

Both deep and shallow tubewells were introduced through BADC, however, since the mid 1980's STW construction and operation has been almost entirely transferred to the private sector. DTWs, on the other hand, have been supplied at heavily subsidised prices and with generous credit facilities. DTW designs have been of be a high investment - long life - low operating cost type, and have also tended to become somewhat elaborate with sophisticated discharge boxes calibrated for flow measurement and expensive pump houses. Government policy is now to privatise the DTW sub-sector, and this will undoubtedly lead to major changes in DTW designs, aimed at reducing capital costs, including:

- shorter screen lengths, and use of thermoplastics;
- simple pump houses and discharge boxes;
- substitution of Chinese and Indian pump sets for Japanese and European ones;
- manual drilling methods;
- reduced quality control.

The objective of this analysis is to evaluate both DTWs and STWs as they would they would be designed for full cost, private sector operation; and explain the fundamental differences between the theory and practice of STW and DTW operation, and hence guide the rational development of policy, especially with regards the wider range of tubewell equipment that will become available under the forthcoming National Minor Irrigation Development Project. The analysis considers only pumps powered by diesel engines, which are expected to remain the dominant source of power in the minor irrigation sector for the foreseeable future.

## 2 Operating Characteristics of Tubewell Pumping Equipment

### Deep Tubewell Pump Characteristics

Pumps, aquifers and wells must be considered as a composite system in order to determine the actual discharge and operating heads (and hence pumping cost) that will be observed in reality. The operation of pumps in deep tubewells is, in principle, the same as for STWs but, by and large, is not complicated by suction restrictions, and thus is described first. A curve relating discharge to head may be defined for both a well, at any particular static water level (SWL) and pumps, as shown in Figure 1. Pump manufacturers provide data for the discharge, efficiency and power requirements at a given rotation speed (which is usually close to the optimum efficiency) as a function of pressure, referred to as the 'pump curve'. The total head ($H_t$) against which a pump in a well operates is:

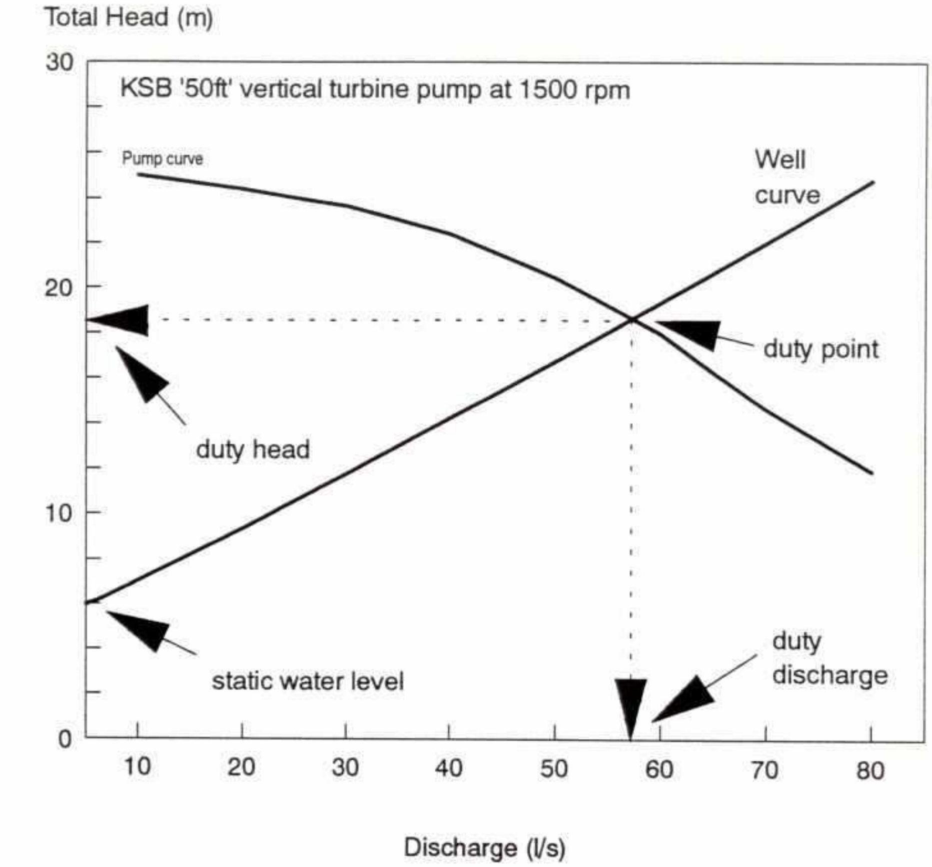


**Figure 1 Determining the Duty Discharge of a DTW**

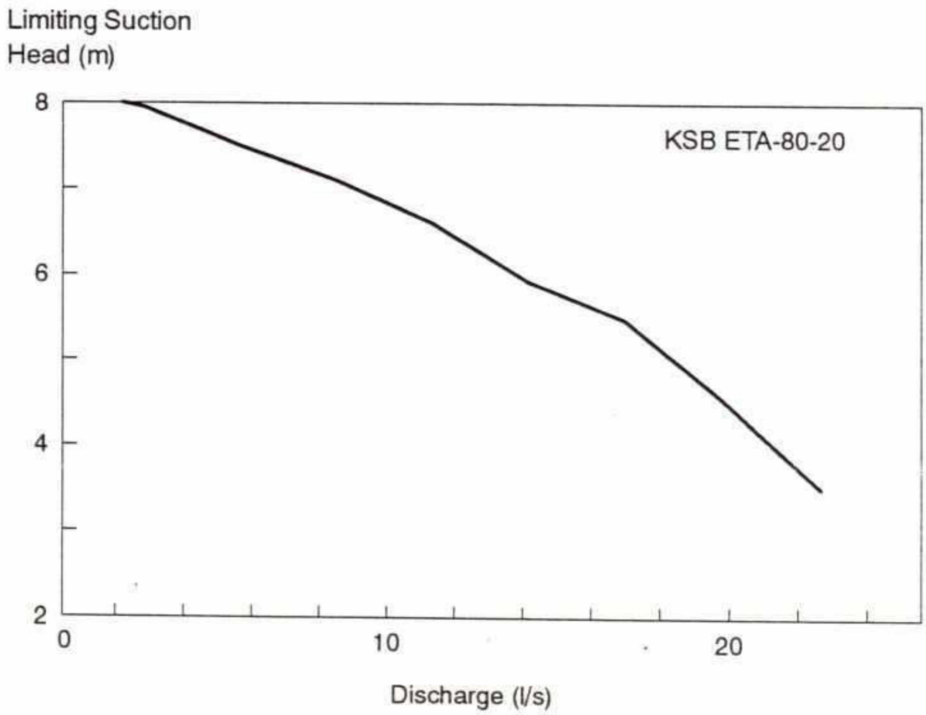


**Figure 2 Suction Limitations for a Typical STW Pump**

$$H_t = SWL + s + H_f + H_d$$

where: $s$ drawdown in the well

$H_f$ friction losses in the pipe work

$H_d$ the lift on the delivery side of the pump

The variation of $H_t$ with discharge is known as the system (or well) curve. The intersection of the system curve and the pump curve defines the operating discharge and head ('duty point') for a given pump speed. The 'duty' discharge will not be same as the nominal or rated capacity of the pump. The only ways to change the discharge are to alter the speed of the engine driving it, or throttle the discharge side of the pump. When the speed of a pump is changed the shape of the pump curve varies in a systematic manner, whereby discharge is directly proportional to speed, head to the square of pump speed, and the power requirement to the cube of pump speed (the 'affinity' laws). Thus the manufacturers performance data may be recalculated for any speed with reasonable accuracy for variations within a factor of two (Linsley and Franzini, 1987). Pumping cost is mainly determined by the 'duty point'. For a well designed DTW, the duty discharge will vary from more than the nominal discharge of the pump at the beginning of the irrigation season, to less than the nominal discharge at the end of season, as the regional water table falls. Thus there are actually a continuous series of well curves bounded the greatest and least water table depths, the intersections of which define the 'duty range' of the pump and well.

**Shallow Tubewell Pump Characteristics**

The characteristics and determination of 'duty discharge' for a STW pump are almost the same as for a DTW pump, except for the inclusion of suction as a limit on discharge. The maximum suction lift ($H_s$) for a pump in a well is determined by the following equation:

$$H_s = H_a - H_f - e_s - NPSH - F_s$$

where: $H_a$ atmospheric pressure

$e_s$ saturated vapour pressure of water

NPSH the net positive suction head, a parameter related to cavitation and proportional to discharge, which provided with manufacturers performance specifications

$F_s$ a factor of safety (usually 0.6m)

Figure 2 shows the resultant plot of maximum suction lift as a function of discharge for a typical STW pump. Determination of the duty point for a STW is that same as for a DTW except that if the lift to the pump intake exceeds $H_s$, then suction will be lost and the continuous discharge of water will be broken, necessitating a reduction of discharge or switching the pump off. The characteristics of STWs under typical aquifer conditions have a number of important implications. The notional '0.5 cusec' (14 l/s) STW is not achievable for surface set pumps, except under the most favourable aquifer conditions. Suction limits are the fundamental constraint on STW discharge. In most areas, deep setting of 2 to 4 metres is required to achieve the nominal discharges. Unless constrained, pumps cannot be operated at their 'design' speeds of 1450 or 1500 rpm. Faced with this situation, pump operators may adopt one of three strategies:

- set the pump in a pit to reduce the suction head. This increases capital costs, may be difficult to maintain in some soils, and takes land out of cultivation;

- throttle the pump outlet to increase the discharge head and hence reduce the flow of water. This method introduces 'unnecessary' pumping costs. This method is probably more common with electrically driven pumps where the motor speed is fixed;

- reduce the engine speed (and also its' power output). This method is thought to be the most common, and increases the capital cost per unit area. Reduced power output at low speed probably accounts for the almost ubiquitous 'over-sizing' of STW engines.

In theory (or at least for the same group of farmers at the same location), the maximum command area that can be served with full irrigation is directly determined by the maximum discharge at time of peak water demand. The maximum discharge that can actually be obtained from STWs under a range of aquifer conditions are shown in Figure 3. the curves shown in Figure 3 should be considered in the light of a water table that will probably fall by 2 to 4 metres during the course of an irrigation season. The low discharges that may be obtained from STWs makes them particularly inefficient (as is well known) on the higher land phases. The sensitivity of STW discharge to suction limits gives rise to a greater variation of discharge during the course of the dry season than is observed with DTWs. Farmers may adopt strategies to reduce these affects by using STWs in a different role within the overall cropping patterns and practices:

- avoid the deepest static water levels (in April) by planting the *boro* crop earlier. This is likely to be lower lands where deep and prolonged flooding has prevented a preceding crop. These low lands will also be have shallower water tables;

- accept the reduced water availability, and deliberately practice partial irrigation, perhaps relying on rains in late March to sustain the crop to harvest, although with substantially reduced yields[1].

## 3 A Techno-Economic Model of Tubewell Irrigation

### The 'Model Aquifer' and Well Design

A simple two layer aquifer system is defined in the model, consisting of an upper aquitard (clay layer) and an aquifer of uniform permeability. No lower aquitards are considered, the aquifer is considered to be unconfined. The volume of water withdrawn by the single well is taken to have no effect on the regional groundwater level. The following parameters are specified:

- mean horizontal permeability (K) of the aquifer;
- thickness of the aquitard;
- depth of water table below ground in the late dry season.

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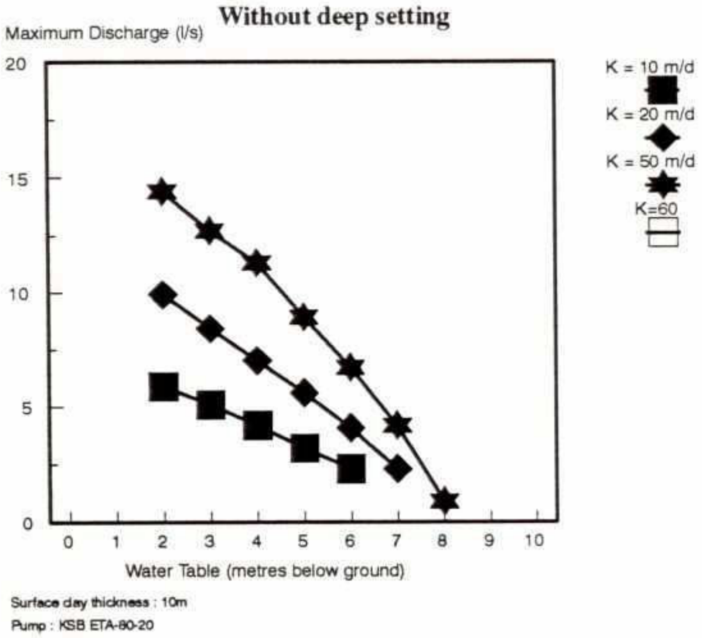
[1] A parallel to this is observed in LLP irrigation where natural water courses dry up towards the end of the dry season.



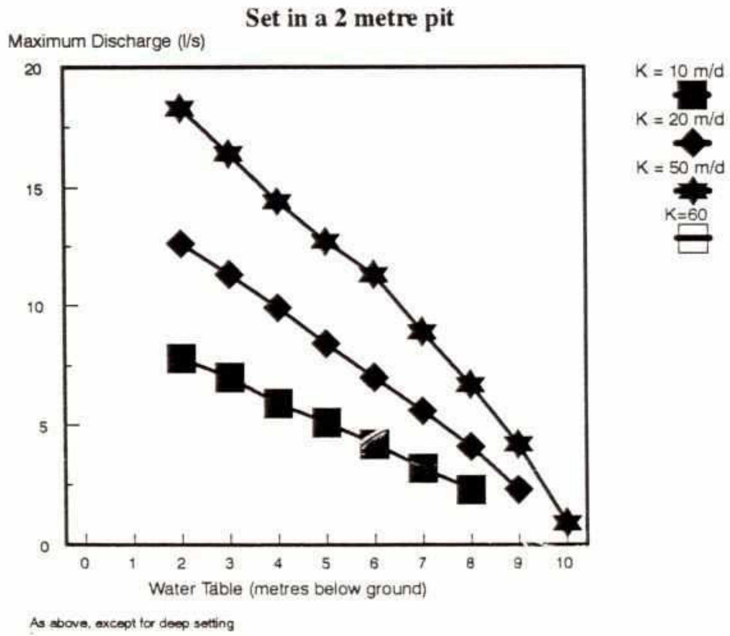




**Figure 3 Maximum STW Discharges**

Well designs follow automatically from the aquifer configuration and the specified length of well screen (assumed to be available in 6 metre lengths). The screen lengths of 12 m for STWs and 24 m for (nominal) 56 l/s DTWs were used as defaults, with default diameters of 10 m and 150 mm.

In the model, STWs may be screened from the end of the first 6 m pipe length below the aquitard. Model DTWs have and upper well casing length calculated as the 'duty drawdown' plus 6 metres. Lower well casing is extended to the top of the aquifer if necessary, but in most cases this is not required because good aquifer conditions (i.e. thin clay covers) are considered. The capital costs for the tubewell (including drilling and testing) are then calculated using cost factors taken from the Minor Irrigation Technologies Study (MMI, 1991).

Drawdown in the aquifer is calculated from a form of the Thiem equation:

$$s_a = \frac{Q}{2\pi KL} . ln \frac{r_e}{r_w}$$

where: L - screen length

$r_e$ - radius of influence (assumes 150m)

$r_w$ - effective well radius (assumes drilling diameter)

The well loss is calculated the equation given by Barker and Herbert (1992a):

$$s_w = Q^2.(\frac{\alpha}{L^4} + \frac{\beta}{L^3})$$

where $\alpha$ and $\beta$ where experimentally determined coefficients for a particular screen type (Barker and Herbert (1992b). Friction losses above the screen were approximated from published tables.

The costs of engines, pumps, drive arrangements, discharge boxes and pump houses were taken from the estimates given in the Minor Irrigation Technologies Study (MMI, 1991) for wells constructed by and for the private sector. The resulting capital costs for DTWs are significantly lower than the full cost prices presently quoted for BADC DTWs (about Tk 600,000). This is not only because of the design modifications anticipated for private sector wells, but also because the present analysis is concerned with areas of relatively good aquifer conditions in areas where STWs and DTWs are in competition, and not in areas in difficult areas where STWs simply cannot operate (for instance a DTW on the Madhupur Tract might be twice the depth of one of the same discharge on the adjacent Jamuna Floodplain).

The costs and performance data were based on the use a (Japanese) Kubota ER900 engine coupled to a KSB ETA-80-20 pump (made in Bangladesh) for the STW, and a KSB vertical turbine pump, with a nominal capacity of 56 l/s at 15 m (made in Bangladesh) coupled through a right angle gear box to a two cylinder (Indian) Ruston engine. Certain missing engine characteristics were assumed by comparison with data for the Lister HR-2

1290

engine. Based on field experience, the (Japanese[2]) STW engines and (Bangladeshi) pumps were assigned a working life of five years, while the DTW engine was assigned a working life of 10 year. The vertical turbine pump and gear box for the DTW are expected to last 15 years (or more). Fuel consumptions were calculated from the manufacturers specific fuel consumption figures and the power generated by the selected engines at the modelled speeds, but de-rated for the degree of under-loading of the engine[3]. Consumption of lubricants were calculated as per manufacturers stated performance. The incidental operating costs such as operator' salary and canal construction were taken as standard per hectare costs based on average values in the Deep Tubewell II (DTW II) Project's 1991 Annual Monitoring Survey (MMI, 1992), with the exception of 'management' which was arbitrarily reduced by half for STWs.

### Costs and Benefits of *Boro* Irrigation

The 'farming' (i.e. non-pumping) costs of *boro* irrigation were taken from the DTW II 1991 Annual Monitoring Survey (MMI, 1992). The costs used in the model were the arithmetic mean of costs on the Old Meghna Estuarine Floodplain, the Young and Old Brahmaputra Floodplains, and the Madhupur Tract. These values are reasonable averages, but it is stressed they are used in the model only for purpose of comparing different tubewell technologies. Similarly no account is taken of payment methods. A summary of the standard parameters used in the techno-economic model are given in Table 1, and should be assumed to apply throughout the following discussion except where stated otherwise.

**TABLE 1**

**Default Parameters for the Techno-Economic Model**

| Parameter | Rate/ Value | Parameter | Rate/ Value |
|---|---|---|---|
| Seeds, fertiliser and chemicals | 4,206 Tk/ha | Aquitard thickness | 10 m |
| labour | 8,154 Tk/ha | Permeability | 20 m/d |
| Draft power | 2,365 Tk/ha | Static water level | 4 m |
| Rice and straw production | 24,290 Tk/ha | STW screen, 12m × 100mmφ PVC | 230 Tk/m |
| Diesel fuel | 14 Tk/l | DTW screen, 24m × 150mmφ PVC | 656 Tk/m |
| Annual pumping | 1200 hours | STW installation | 100 Tk/m |
| Irrigation water requirement | 800 mm | DTW installation | 780 Tk/m |
| Discount rate | 12% | STW engine and pump | 26,500 Tk |
| Period of economic analysis | 15 years | DTW engine, gear box and pump | 200,000 Tk |

2 Chinese STW engines are significantly cheaper, but generally have to be replaced after two years. Similarly some European engines (e.g. Ruston) last much longer, but are significantly more expensive.

3 Using de-rating data for the Lister HR-2.

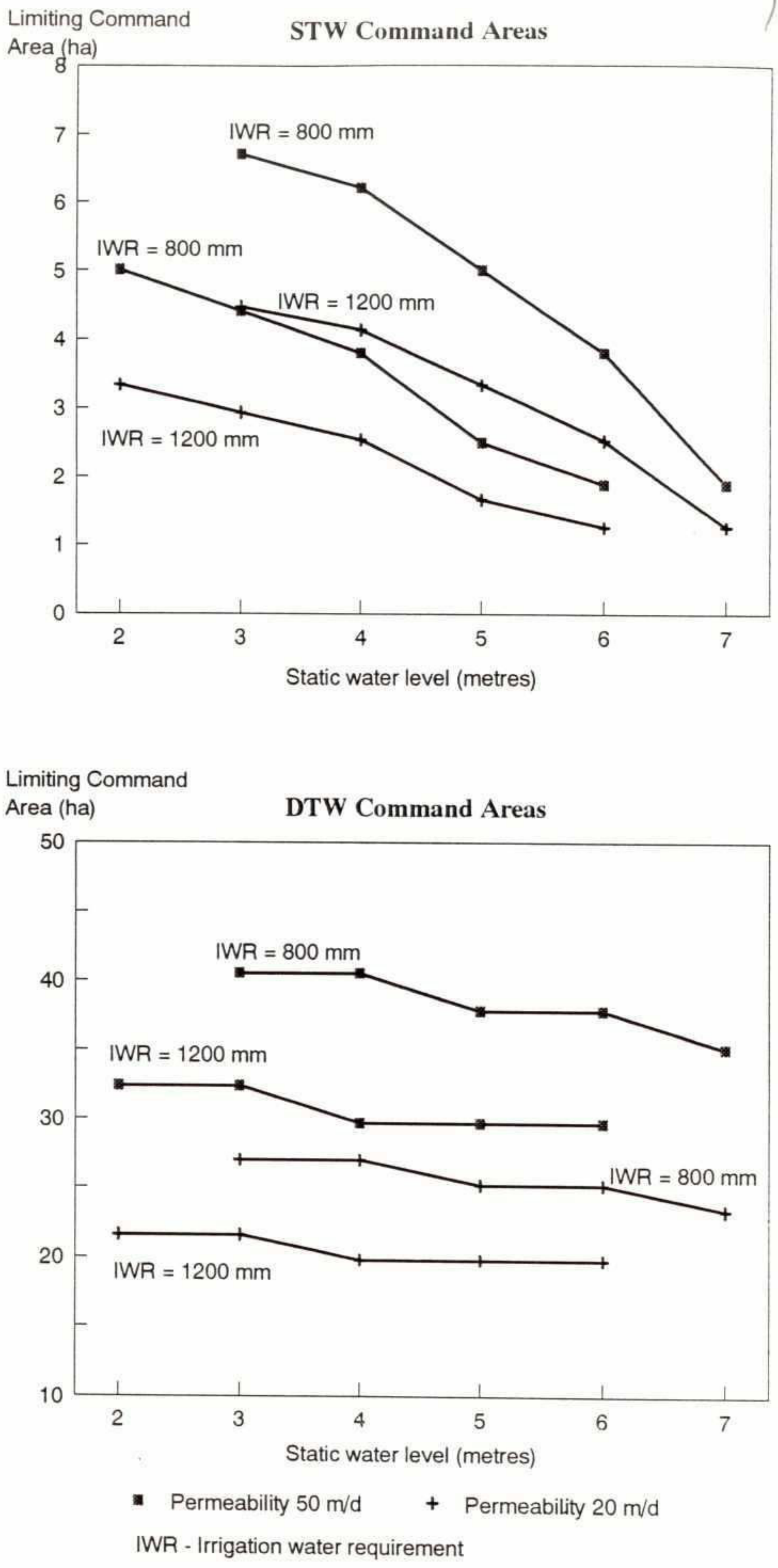
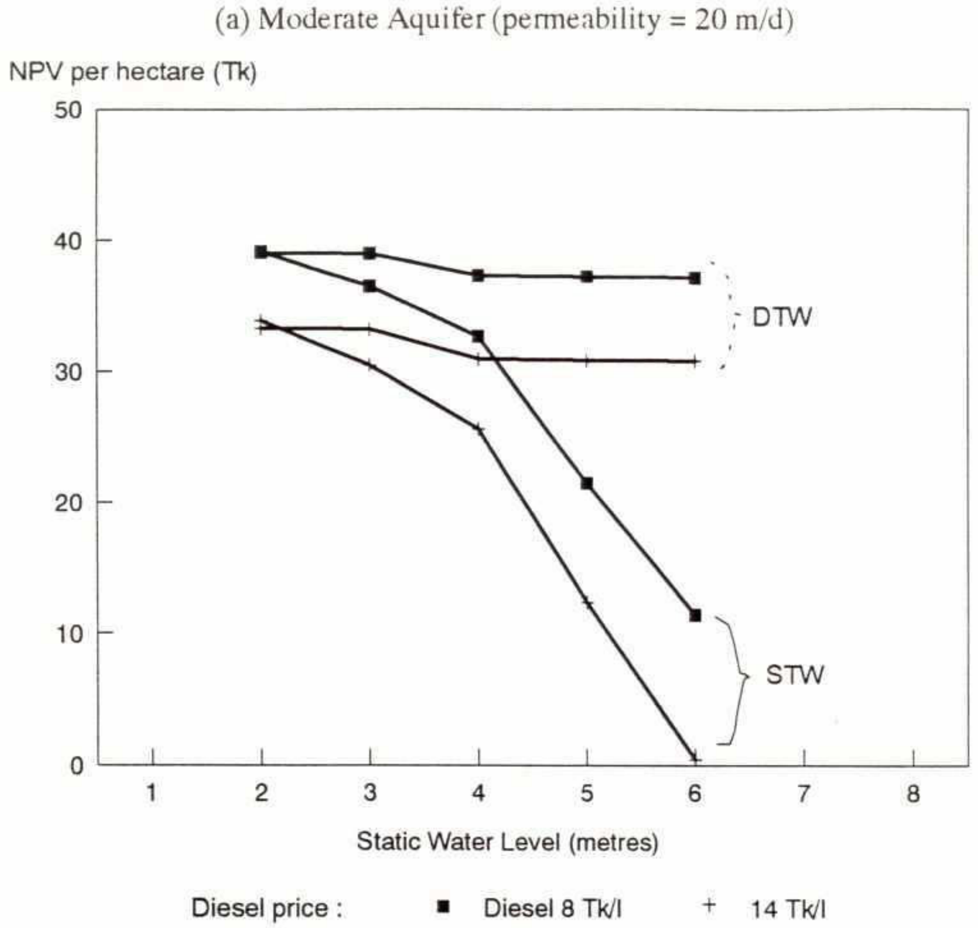



**Figure 4 Comparison of Limiting Command Areas under Varying Aquifer Permeabilities and and Irrigation Requirements**



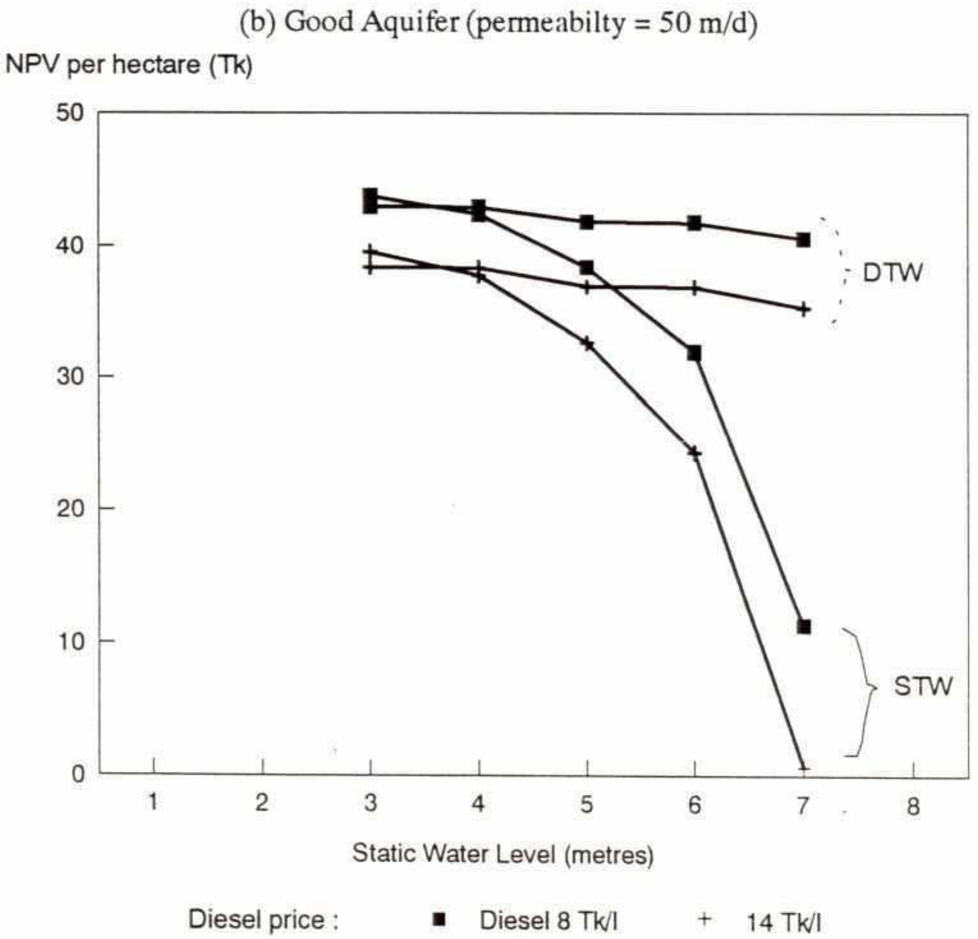




**Figure 5 Economic Comparison of Deep and Shallow Tubewell Irrigation**

Economic analysis was carried out using conventional discounted cash flow techniques, and comparisons are based on the NPV of costs and benefits per hectare. It is emphasised again that this is a partial economic analysis (no with and without project comparison) aimed at determining the economically preferred mode of irrigation under different conditions.

## 3 Results

The different operating characteristics of STW and DTW pumping equipment leads to a greatly different sensitivity to hydrogeological parameters. As shown earlier, maximum STW discharges fall off rapidly with increasing depth to water and decreasing aquifer permeability (i.e. more drawdown), and so must command areas and hence the economic viability. Figure 4 shows the limiting command areas for deep and shallow tubewells under good and moderate aquifer conditions, and for typical (800 mm) and high (1200 mm) irrigation water requirements. The different discharge responses of the well types is crucial to explaining the economic returns to irrigation shown in Figure 5. Under favourable water level conditions the returns are very similar, however, as the water level falls large differences in economic performance become apparent long before suction limitations render STWs inoperable. DTW irrigation (viewed in isolation) is observed to be economically preferable to STW irrigation under almost all conditions. It is important to note that the STW benefit curve does not have a smooth slope, but tends to follow the DTW closely until a critical water table depth and then plunges steeply into a loss making condition.

Figure 5 also shows the effect of diesel price variations, including the present price of 14 Tk/l and the pre-Gulf War price of 8 Tk/l. Diesel price, of course, has a dramatic effect on the overall profitability of irrigation, but the important conclusion from this comparison is that it has little effect on the relative profitability of DTWs and STWs, and yet the post Gulf War price increase may have reduced the economic limit (measured in terms of water table depth as a possible zoning criterion) of STW irrigation by as much as a metre.

It is generally assumed that the success of force mode tubewell development by the private sector depends largely on the ability to reduce to capital cost (per hectare), as in this analysis. The influence of DTW capital cost on economic viability was examined by applying an arbitrary multiplier to the capital and replacement costs of the DTW until the net benefits of the two modes were equal. It was found that in a good aquifer (K=50 m/d) with a water table at 5 metres the capital cost of a DTW may be increased by up to 83% (to Tk 550,000), and in a moderate aquifer (K=20 m/d) with a water table of 4 metres the cost of a DTW may be increased by up to 50% (to Tk 473,544)

It is common practice to use STW engines for other purposes, such as powering country boats or power looms, whereas DTW engines are found to be too heavy and cumbersome to be put to alternative uses. This difference must influence the true economic evaluation of STW irrigation. Although this is basically beyond the scope of the paper, a simple test of its potential impact was carried out by adding a lump sum for non-farming operating profit to the annual income of the STW. In a good aquifer (K=50 m/d) with a water table at 5 metres the required income to equate the net benefits of DTW and STW irrigation is Tk 4,250 a year, and in a moderate aquifer (K=20 m/d) with a water table of 4 metres the required income is only Tk 2,900.

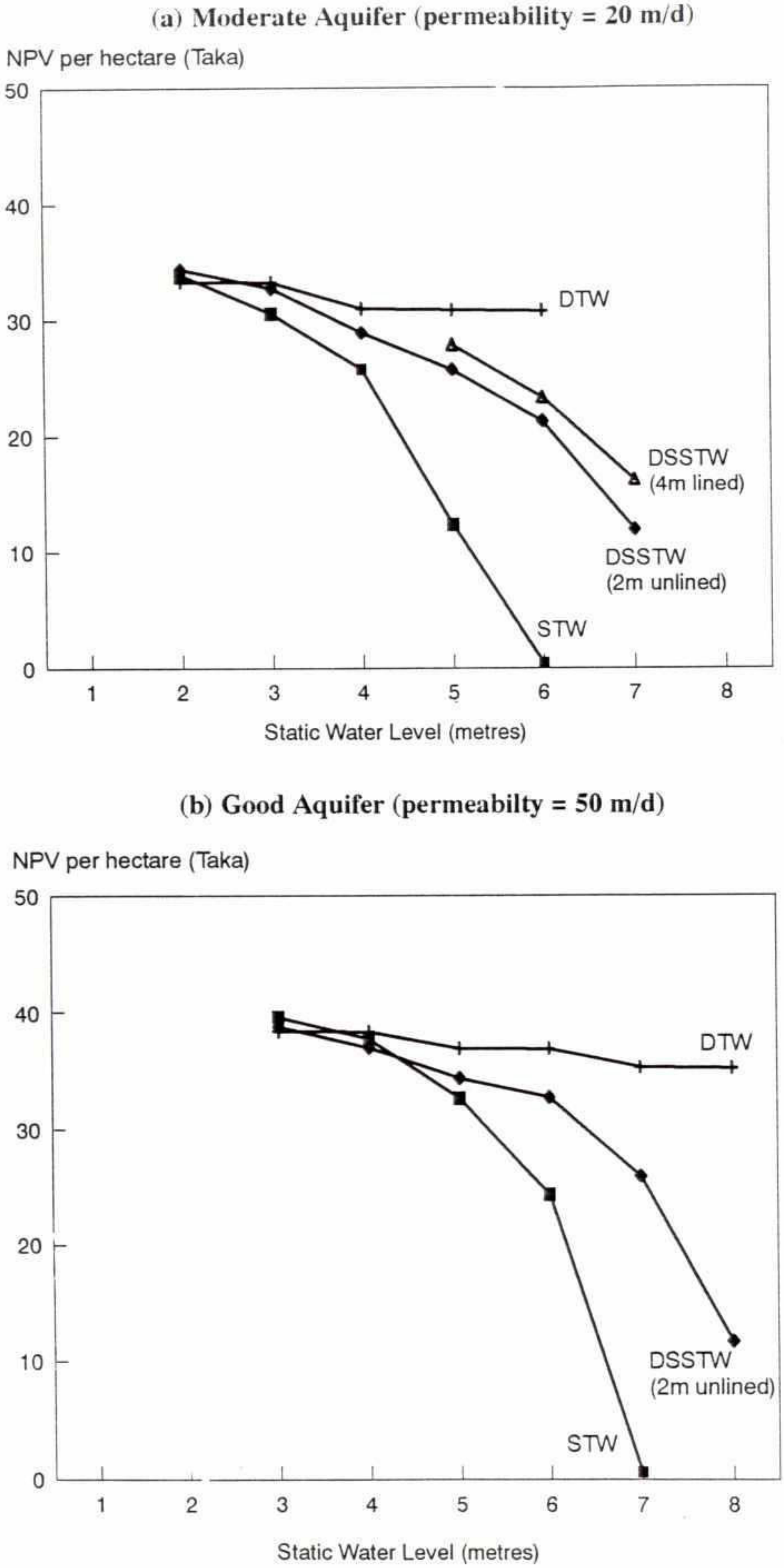



**Figure 6 Economic Evaluation of Deep Setting of Shallow Tubewells**

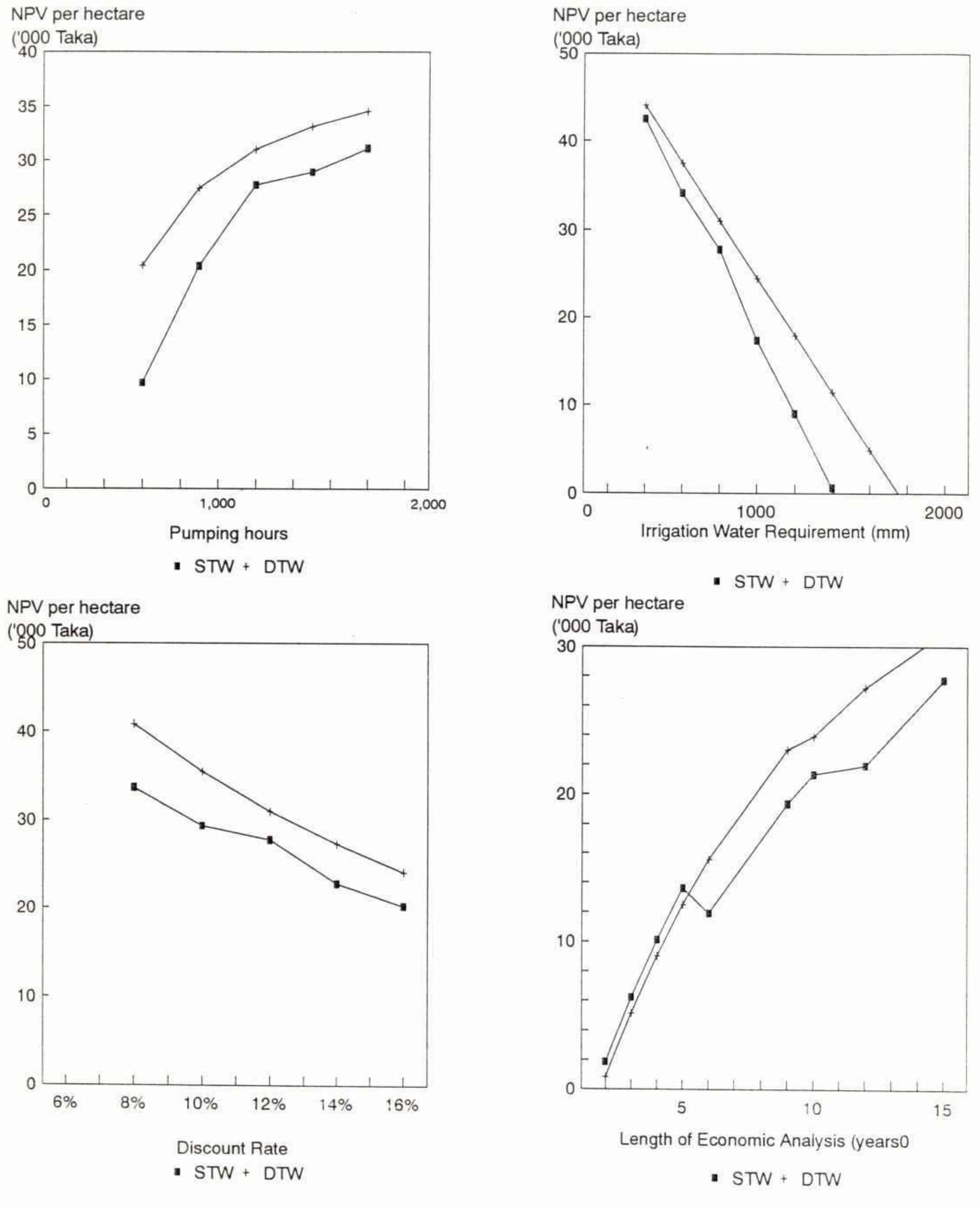



**Figure 7 Sensitivity Analysis**

Figure 6 shows the influence of deep setting on the economics of STW irrigation. Both unlined deep setting to 2 metres and lined pits of 4 metres depth have been considered, under both good and moderate aquifer conditions. For a 2 m pit, the effect is basically to shift the benefit curve to the right, moving the point at which the curve plunges steeply by almost as much the depth of the pit. However, while the shift is small it may well be critical to the profitability of STW irrigation over large areas of Bangladesh. That the shift is less than the depth of the pit is highly significant and points to declining returns from attempts to chase a progressively falling water table. This is illustrated by the case of the 4 m lined pit, which shows a small economic improvement over the 2 m unlined pit. Under these conditions, while high discharges may be maintained by increasing the engine speed, the type of pump appropriate for mounting on the surface is forced to operate under very inefficient conditions. Very deep DSSTWs will need larger pumps which will consume more power, and have higher capital costs. This warrants a separate analysis, but it is likely that the economic potential of pits more than 3 metres is limited.

Figure 7 shows the sensitivity of the general analysis given above to irrigation water requirements, pumping hours, discount rate, and the period of economic analysis; and leads to the following conclusions:

- Other things being equal, DTW irrigation becomes economically better where the irrigation water demand is highest. However, it should be noted that this ignores transmission difficulties on sandy soils, which may in fact negate this apparent advantage. In areas of minimum irrigation demand (e.g near the Haor Basin) the differences are insignificant.

- The differences between the returns on DTW and STW irrigation decrease as the as the pumping hours increase.

- Discount rate has negligible influence on the relative performance of DTW and STW irrigation.

- The length of the economic analysis is extremely important. DTW irrigation does not become preferable until five years (the point when the STW pump set needs it first replacement).

## 4 Discussion

### Comparison with Actual Performance

It is instructive to compare the model predictions of performance with actual performance, for which we may use the example of Comilla District, an area where agriculture and all forms of irrigation are well developed. Model predictions of command area are based on a permeability of 20 m/d, a water table of 4 metres and an irrigation requirement of 800 mm; and are compared with actual command areas in 1991 (AST/CIDA, 1991) in Table 2.

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**TABLE 2**

**Actual and Predicted Command Areas in Comilla District**

| Irrigation Mode | Predicted Command ha | Actual Command ha | Difference |
|---|---|---|---|
| DTW | 29.7 | 23.8 | 80% |
| STW | 3.8 | 5.9 | 155% |
| DSSTW (2 m pit) | 5.3 | 6.8 | 128% |

While the predicted values are broadly similar to the actual ones, the pattern of the differences are highly significant. These figures also challenge the widespread claims of under-use of capacity in irrigation. DTWs (all of nominal 56 l/s capacity) are under-used by about 20% compared to what might be considered reasonable. DSSTWs have slightly higher commands than surface set STWs, but not as much higher than might be predicted, supporting the view that deep setting is being used more as a reserve capacity than as a deliberate strategy to increase command areas. In terms of efficient use of capacity the performance of STWs and DSSTWs appears so impressive as to verge on the incredible. This is not to suggest that the surveys are in overall error, but rather to suggest that STWs are associated with different farming system than DTWs. The differences in Table 2 would imply that STWs would have to pump for perhaps twice as long as DTWs, a proposition that is not supported by the available data on pumping hours. It is suggested that STW irrigators practice a conscious policy of under-irrigation, planting a large area at the start of the season when the well's discharge is good knowing that the well will not be capable of supplying all the water required later, and hoping for some rain late in the dry season to produce a reasonable yield from the crop. Under these conditions, rice yields at STWs would be lower than at adjacent DTWs, but since the percentage yield reduction declines more slowly than the percentage of water applied (as a proportion of the theoretical water requirement), this may lead to a different optimum farming practice for different modes of irrigation.

**Implications for Force Mode Tubewell Design**

The preceding analysis, indicates that DTW irrigation, conducted on the basis of minimum capital cost designs, and assuming a farming practice of full irrigation, and making full use of the available capacity is economically preferable to STW irrigation, even in areas with the best aquifer conditions (which in recent years have been treated as 'unsuitable' for DTWs). On the other hand, comparison with actual performance indicates that STWs operate with more efficient use of capacity. Private sector STWs have undoubtedly been a great success, and the difference between the theory and practice is probably explained by the fact the standard assumption of comparative analyses, that of *ceteris paribus* (other things being equal) does not apply. Farmers practice, and will probably continue to practice, an apparently sub-optimum irrigation system for a variety of reasons, including:

- a smaller number of farmers need to be organised to irrigate the maximum possible area. For 50 - 75 l/s DTWs this might involve more than a hundred people, certainly more than optimum from a managerial perspective.

- small diesel engines used for STWs and DSSTWs may be used for other purposes during the other eight months of the year. An operating profit of only a few thousand taka a year from these activities can turn STWs into the economically preferred mode of irrigation.

- critically, although long term economic benefits may be lower, STW irrigation runs into profit earlier.

- in some areas, the supply of DTWs through BADC could not keep pace with demand.

Nevertheless, the results of the are encouraging for the development for the promotion and development of force mode tubewells by the private sector. The results indicate that the force mode irrigation should be possible at about the same cost (or better) as STW irrigation, but that it will take longer for the operation to run into profit (unless good credit facilities are available). Important lessons may be learned from the STW experience:

- lower capacity tubewells may achieve full use of the installed capacity owing to the simplified management requirements, and unlike STWs force mode wells would not be obliged to adopt the under-irrigation compromise since their maximum discharges would be more constant during the irrigation season.

- lower capacity tubewells would require smaller diesel engines (than the current DTWs) that could be put to other uses outside the irrigation season (i.e. the majority of the year) and earn added profits for the organising group (i.e. the investors in the tubewell should not see it as simply an irrigation business).

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## APPENDIX 1

### Sample Output of Model for the Default Conditions

| | STW | DTW |
|---|---|---|
| Screen Length (m) | 12 | 24 |
| Screen roughness parameter $\alpha$ ($s^2/m^6$) | 156 | 17 |
| Screen roughness parameter $\beta$ ($s^2/m^5$) | 3750 | 735 |
| Drilling depth (m) | 24 | 50 |
| Capital cost of well | 9,415 | 115,696 |
| Capital cost of pump set | 26,500 | 200,000 |
| Specific drawdown (m/l/s) | 0.0051 | 0.0025 |
| Limiting Command Area (ha) | 3.8 | 29.7 |
| Actual Discharge (l/s) | 6.97 | 55 |
| Total Head (m) | 7.8 | 18.6 |
| Pump speed | 1170 | 1500 |
| BHP requirement | 1.4 | 17.5 |
| BHP output | 4.8 | 22.6 |
| Engine loading factor (load/output) | 0.30 | 0.77 |
| Fuel consumption (underloading) factor | 0.38 | 0.79 |
| Specific fuel consumption (g/HP.Hr) | 244 | 178 |
| Fuel Consumption (litres per m3) | 0.021 | 0.019 |
| Cost of Fuel (Tk) | 8,954 | 63,941 |
| Cost of Lubricants (Tk) | 730 | 4253 |
| Annual operating cost (Tk) | 68,317 | 540,245 |
| Annual income (Tk) | 91,432 | 721,413 |
| Total capital cost (Tk) | 35,915 | 315,696 |
| Benefit / Cost ratio | 1.18 | 1.23 |
| NPV of benefits per hectare (Tk) | 25,728 | 30,971 |