Government of India
Government of Andhra Pradesh
Ministry of Panchayati Raj and Rural Development

Government of the Netherlands
Ministry of Foreign Affairs
Directorate General of
International Cooperation

RURAL WATER SUPPLY
ANDHRA PRADESH

WATER RESOURCES STUDY AP-III

VOLUME I - EXECUTIVE SUMMARY

IWACO

Consultants for Water & Environment

Head Office:
P.O. Box 8520
3009 AM Rotterdam
The Netherlands

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8000003

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1. INTRODUCTION

1.1 BACKGROUND

The Government of India (GOI) has requested financial support from the Government of the Netherlands (GON) for the implementation of an integrated rural water supply and sanitation project in the Nalgonda District, Andhra Pradesh. This AP-III project is to cover a total of 226 scarcity and fluoride affected villages. The project proposed the construction of two piped water supply systems with the Nagarjuna Sagar Left Bank Canal as raw water source.

An appraisal of the proposed project was carried out on behalf of DGIS in October 1991. The main recommendation of the appraisal team was to carry out a more detailed study of the water resources in and near the project area as locally available water might reduce the cost and increase the reliability of the proposed system. A large scale piped system can possibly be avoided completely.

The present volume 1 of the report describes the findings of the water resources study that was carried out to estimate the quantities of reliable ground and surface water that are available in or near the project area. A limited number of water source alternatives for the drinking water system will be presented to show the supply options of the project area.

The water resources study has been carried out by Mr. J.J.van der Sommen, hydrogeologist of IWACO, with the support of Mr. Krupanidhi, retired Director of the Central Groundwater Board. The study was done in close cooperation with the Panchayati Raj Engineering Department and in consultation with the Netherlands Assisted Projects (NAP) Office in Hyderabad. Specific tasks were carried out by the Andhra Pradesh State Remote Sensing Agency, APSRAC (Satellite image interpretation and fieldwork) and the Central Groundwater Board, CGWB (geophysical measurements). Among other organizations that participated in the study are State Groundwater Department (SGWD), Irrigation Development Cooperation (IDC) and the Institute for Preventive Medicine (IPM).

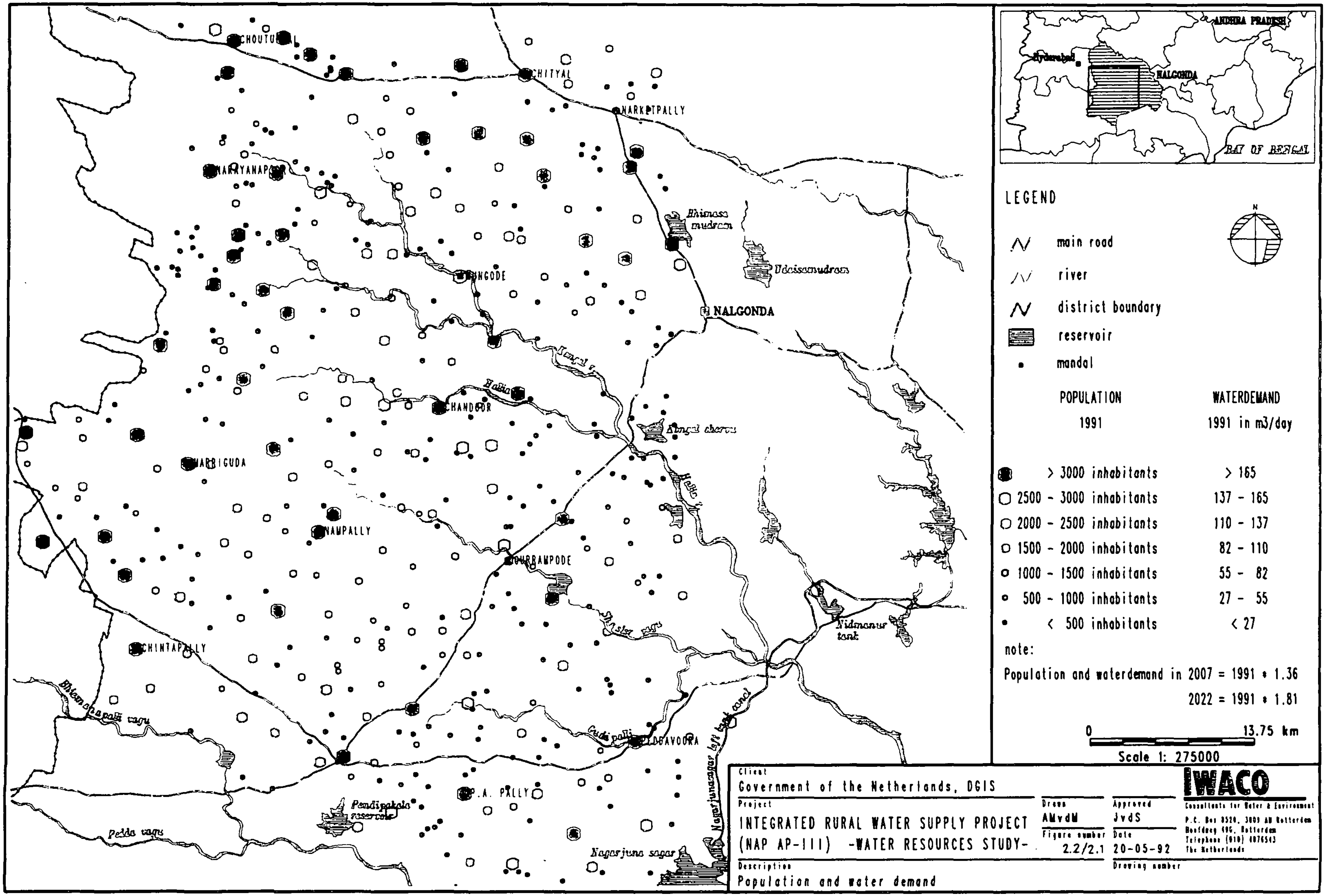
2. WATER REQUIREMENTS

2.1 POPULATION AND WATER DEMAND

The study area covers an area of 2,750 km² and is located in the Nalgonda District (figure 2.1). It includes 16 mandals, 226 villages and 336 hamlets. Population projections are estimated using the 1991 census results and assuming a growth rate uniform over the area of 2%. Per capita supply is 55 liters per day including provision for 25% house connections,cattle troughs and sanitation facilities.

Table 2.1: Population and water demand

	1991	2007	2022
population	458,000	623,000	829,000
water demand (m³/day)	25,200	34,200	45,600



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Project: INTEGRATED RURAL WATER SUPPLY PROJECT (NAP AP-III) -WATER RESOURCES STUDY-

Drawn: AMvdM | Approved: JvdS | Figure number: 2.2/2.1 | Date: 20-05-92 | Drawing number:

Description: Population and water demand

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2.2 EXISTING RURAL WATER SUPPLY

The water supply to all the villages in the project area presently originates from groundwater resources. The following schemes are in use:

- Bore wells fitted with hand pumps.
- Mini protected water supply Schemes (MPWS). Schemes with a single point of distribution.
- Protected Water Supply Schemes (PWSS). Schemes with a distribution system supplying one to three villages.

There are 73 MPWS and 29 PWSS schemes and over 2500 hand pumps. In 12 villages defluoridation plants are in operation or under construction.

Many of the systems are not in a good state as wells reportedly fall dry or need repair. The reasons of the frequent failure of the wells is a combination of technical and hydrogeological factors. A proper constructed borehole of adequate depth with a proper hand pump should not fail. This holds also for boreholes used in MPWS and PWSS schemes. Here proper hydrogeological well siting is of great importance and can avoid many of the problems encountered. Other boreholes have a high fluoride content and new sources need to be located.

Defluoridation plants have been established at several places in the area under the National Drinking Water Mission Programme. Although some difficulties are encountered by the PRED the plants function well. Field measurements indicated that the produced water is well within the permissable fluoride limits. It was observed however that at some distance from plants boreholes are present with low fluoride concentration. A large area should be investigated to locate wells with permissible fluoride content, before a decision on defluoridation is taken.

3. WATER RESOURCES

3.1 CHARACTERISTICS OF THE STUDY AREA

The Nalgonda District is one of the 23 districts of Andhra Pradesh. With a total population of 2.94 million spread over 1,115 villages and 10 towns and about 83% of the population being rural and 40% of the area being sown, the district is, by and large, agrarian. Due to the low annual rainfall (720 mm) and large rainfall variability the district is chronically drought affected. Many parts of the district are afflicted by fluorosis due to a high fluoride content in the drinking water.

The area is underlain by fractured rocks, covered with a thin weathered layer. Groundwater is exploited by a large number of dug wells and boreholes used for irrigation and drinking water supply. Except for tanks and reservoirs there are no surface water resources during most of the year.

3.2 SURFACE WATER RESOURCES

Water from the Krishna river, stored behind the Nagarjuna Sagar dam is the only source of surface water available in adequate quantity and quality. There are no alternative surface water sources even far outside the project area. The water from the Krishna river can be tapped in three ways:

- from de Nagarjuna Sagar Left Bank Canal. Intake sites shall be located at Awal and Nidamanur as summer storage tanks are present. These will be required to store water during the canal closure period of 75 days;

- *from the future Sri Sailam* Left Bank Canal that runs through the project area. The advantage is that a number of villages can be supplied under gravity and the pumping head and distance to the remaining villages can be reduced. The disadvantage is that it is still not certain if and when the project will be completed. Completion is not likely before the year 2005;

- from the future pipeline to Hyderabad. Water can be supplied under gravity to the project area from Mal. Agreement probably can be reached for 30,000 m³/day. However, the project has not yet started and is not likely to be completed before the year 2000.

3.3 GROUNDWATER

3.3.1 Water quality

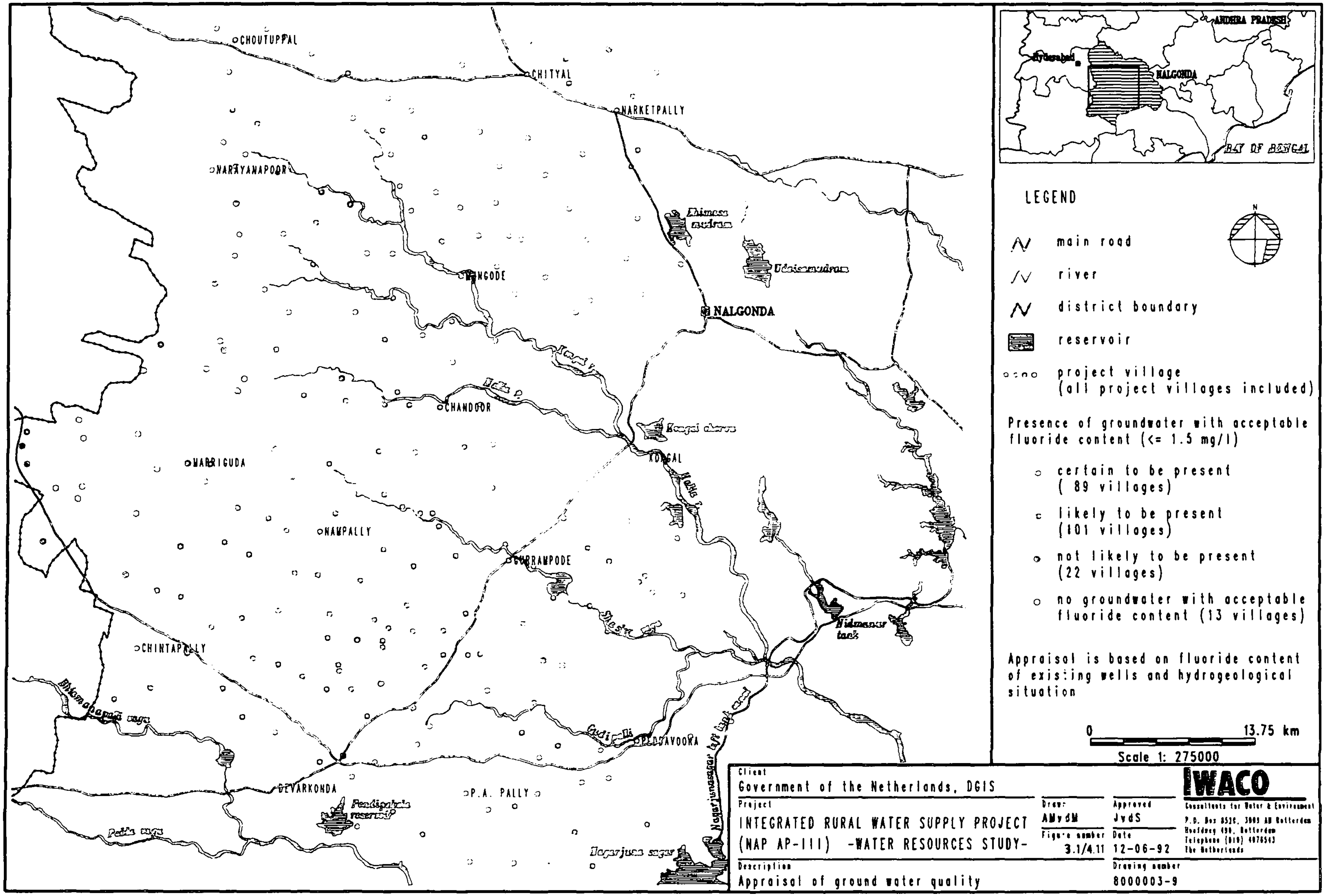
The main problem hampering the development of drinking water supply from groundwater is the occurrence fluoride in unacceptable high levels (> 1.5 mg/l). The occurrence of fluoride in groundwater is closely related to its presence in the rocks in the area and to the way it is transported by the groundwater.

Fluoride is present in the granites in the western part of the area and some isolated hills. It is released through weathering and can be transported by the groundwater and subsequently be partly redeposited as carbonate deposits (or kankar) in discharge areas. In large fracture zones that are in connection with fluoride containing source rock and serve as conduits for groundwater flow, fluoride concentrations are high. In local recharge areas not in connection with the regional fracture system, low fluoride concentrations are found.

The distribution of fluoride seems highly erratic even among waters of different wells in one village. By analyzing groundwater flow paths however a logic pattern of fluoride distribution emerges that is essential in locating wells with acceptable fluoride levels. Using detailed topographical maps on which recharge and discharge areas can be delineated, aerial photographs to examine the fracture pattern and field fluoride measurements of existing wells, the fluoride distribution can be mapped. It appeared that areas with low fluoride content occur near most villages.

A different case is the diluting effect surface water can have on fluoride concentration in groundwater. Wells have in general low fluoride content in the immediate vicinity (less than 50 m) of surface water bodies that are low in fluoride. High fluoride surface waters are found mainly in the west while in the north-east, tanks from north-south flowing streams have low fluoride content.

An appraisal of the groundwater quality is made for each village in the study area using this approach. The possibilities of locating groundwater resources with acceptable fluoride levels (≤ 1.5 mg/l) has been assessed within a radius of 2.5 km of the village. The result of this analysis is presented in figure 3.1. In 190 villages water with acceptable fluoride levels can be found within 2500 m from the village centre. It can be assumed that it is still within most village limits. In 36 villages no good groundwater can be found within 2,500 m, but it is likely that for 12 villages good quality groundwater can be located within 5,000 m.


CHOUTUPPAL
CHITYAL
NARKETPALLY
NARAYANAPOOR
NALGONDA
CHANDOOR
KONGAL
MARRIGUDA
NAMPALLY
GURRAMPODE
CHINTAPALLY
DEVARKONDA
P.A. PALLY
PEDDAVOORA
Udaisamudram
Nidmanur tank
Nagarjuna sagar
ANDHRA PRADESH
Hyderabad
NALGONDA
BAY OF BENGAL
N
LEGEND
main road
river
district boundary
reservoir
project village
(all project villages included)
Presence of groundwater with acceptable fluoride content (<= 1.5 mg/l)
certain to be present
(89 villages)
likely to be present
(101 villages)
not likely to be present
(22 villages)
no groundwater with acceptable fluoride content (13 villages)
Appraisal is based on fluoride content of existing wells and hydrogeological situation
0
13.75 km
Scale 1: 275000
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Description
Appraisal of ground water quality
Drawing number
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3.3.2 Groundwater quantity

The occurrence of groundwater in the study area that is underlain by hard rock, depend on the intensity of fractures and fissures and on the thickness of the weathering layer on top of the rocks. The fractures in the hardrock can be seen as collectors of water that is stored in the overlaying weathered layer. The intensity of fractures and the thickness of the weathered layer is highly variable. A first impression of these two parameters that characterise the groundwater system has been obtained by the interpretation of remote sensing data and field reconnaissance. A hydrogeomorphological map has been prepared showing the thickness of the weathered layer and fracture intensity. Detailed information could be obtained from the seismic refraction method that was applied at test sites to determine the thickness of the weathering layer.

The weathered rock aquifer occurs within 35 m depth and is usually 10 to 15 m thick. It has a low transmissivity, typically 20 - 30 m^2/day. Dug wells in these aquifers yield general 50 to 180 m^3/day. Fractured rock aquifers show higher transmissivities in the range of 80 to 300 m^2/day and yields of boreholes in fractures range from 200 to 500 m^3/day. Most of the irrigation wells are of this type.

From recharge studies in the area it appeared that it is unlikely that the recharge over an entire catchment area will be more than 15% of the annual rainfall and probably it is less, somewhere around 10%. Recharge will vary across a catchment being higher in the recharge areas (15-20%) than in the lower situated discharge areas (1-5%). Groundwater recharge can increase substantially in the vicinity of tanks as a result of seepage.

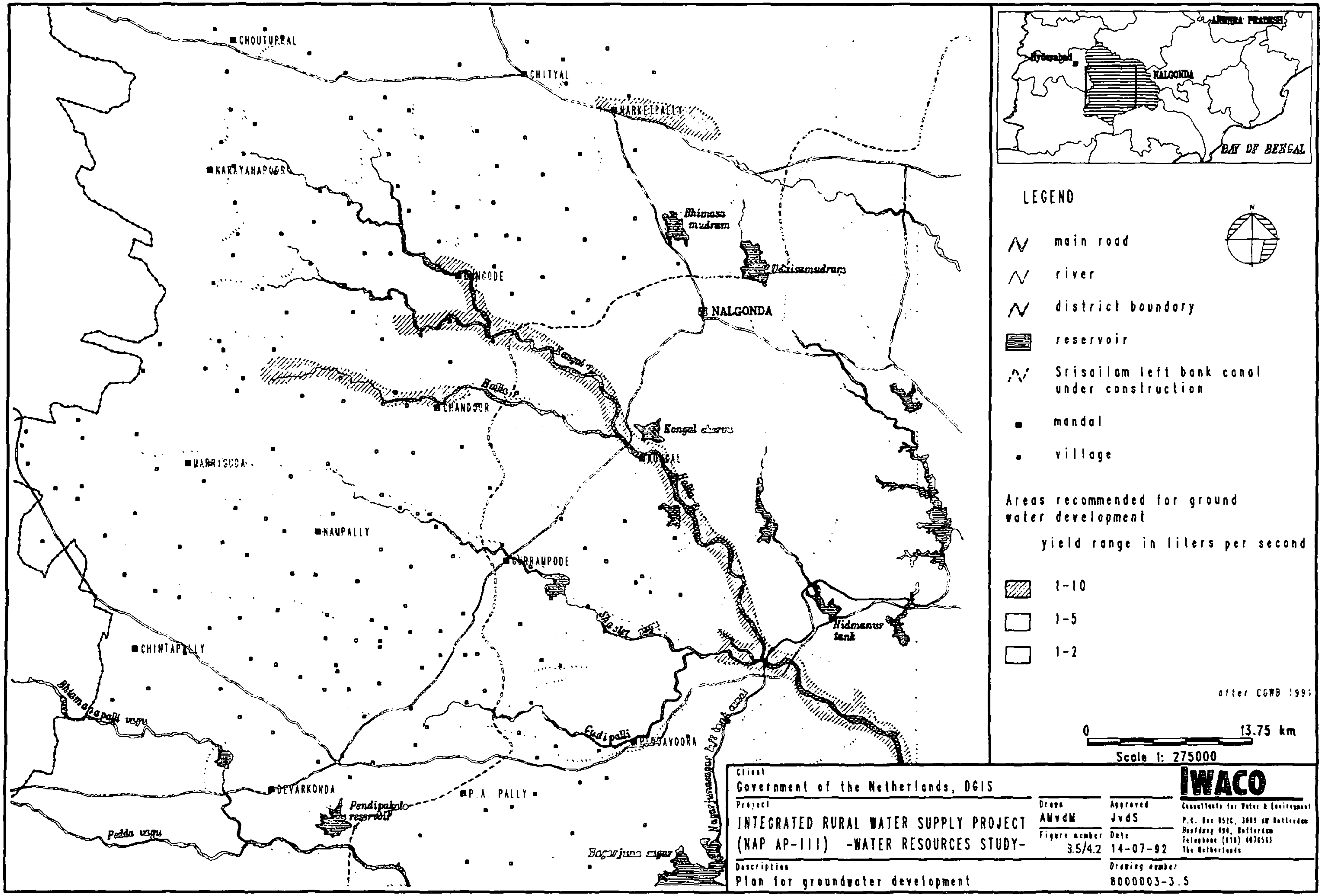
Natural water level fluctuations range from 1 to 6 m. The groundwater system has a low storage capacity. As can be seen from the water level hydrographs the groundwater system is sensitive to rainfall fluctuation. There is no trend of declining water levels at a regional scale. The water level follows the topography and flows towards the nearest river. In valley bottoms water levels are close to the surface (less than 3 m).

The large areal and temporal variation of recharge and the heterogeneity of the aquifers makes it difficult to give hard figures of groundwater potential. The method that is recommended by the Groundwater Estimation Committee in India is based on the groundwater level fluctuation method. According to this method the actual groundwater development in the study area is only 47%. It indicates that there is sufficient water left to cover all drinking water requirements and to make large scale groundwater development for irrigation possible. The CGWB has made groundwater development plans for the region that indicates likely yield ranges within the study area (figure 3.2). According to these plans more than 300 high yielding irrigation boreholes (3.5 to 35 m^3/hr) and 3100 moderately yielding wells (3.5 to 17.5 m^3/hr) are feasible.

At a regional scale this may well be valid ,on a local scale results should be interpreted with caution. At the scale of a sub-basin of 20 to 50 km^2 the terms of the water balance should be in broad agreement, lest over exploitation will occur. A preliminary assessment of groundwater has been carried out at such a scale, examining each village.

3.3.3 Groundwater development for public water supply

The quantity aspects of groundwater availability in the area is closely related to the quality aspects. Fracture zones that can furnish high well yields contain groundwater rich in fluoride, while in the local recharge areas poor in fluoride wells have relatively low yields. On a regional scale there is a large groundwater potential. Problems of over exploitation can however occur locally. Detailed design should be made based on local aquifer conditions and results from pump test. Where it is not likely that extensive irrigation will occur wells should preferably located.



ANDHRA PRADESH
Hyderabad
NALGONDA
BAY OF BENGAL
LEGEND
main road
river
district boundary
reservoir
Srisailam left bank canal under construction
mandal
village
Areas recommended for ground water development
yield range in liters per second
1-10
1-5
1-2
after CGWB 1991
0
13.75 km
Scale 1: 275000
CHOUTUPPAL
CHITYAL
NARKETPALLY
NARAYANAPOOR
Bhimasamudram
Udaisamudram
NALGONDA
MUNUGODE
Kengal r.
Halia r.
CHANDOOR
Kengal cheruvu
KONGAL
MARRIGUDA
NAMPALLY
GURRAMPODE
Shaslet
Nidmanur tank
CHINTAPALLY
Bhimanapalli vagu
Gudipalli
PEDDAVOORA
Nagarjunasagar left bank canal
DEVARKONDA
P. A. PALLY
Pendipakala reservoir
Pedda vagu
Nagarjuna sagar
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Drawn
AMvdM
Figure number
3.5/4.2
Approved
JvdS
Date
14-07-92
IWACO
Consultants for Water & Environment
P.O. Box 8520, 3009 AM Rotterdam
The Netherlands
Description
Plan for groundwater development
Drawing number
8000003-3.5

Recharge areas are more suitable and as soils are poor and well discharge is often too low for efficient irrigation, private abstractions of any importance are not likely. If necessary wells can be protected by water sanctuaries (50 to 200 m around the well).

The possibilities of groundwater exploitation for drinking water has been assessed for each individual village. The following procedure has been followed:

- Overall assessment of the hydrogeological situation using topographical maps, thematic maps obtained from remote sensing analysis, hydro geomorphological maps, groundwater abstraction maps and water quality data and field measurements.

- Examination of the possibilities of exploitation of groundwater with acceptable fluoride content (< =1.5 mg/l F) within 2500 m from a village and selection of well type that is most appropriate. Four well types and hydrogeological standard situations have been defined that fit best the specific requirements of drinking water wells and the characteristics of the area:

  1 Fractured rock bore well
  2 Bore wells in valley fill or dike rock
  3 Surface water infiltration dug well
  4 Recharge area dug well (or dug cum bore)

- The most likely discharge category depending on the hydrogeological situation has been assigned to each well type. Given the village water demand the number of wells is calculated. A conservative approach is adopted as the individual discharges of wells are set very low (40 m^3/day for recharge area wells for example).

  A defluoridation plant per village has been provided in case no low fluoride water is found within 2,500 m.

4. WATER SUPPLY ALTERNATIVES

The groundwater supply alternatives are compiled out of the local village supply options. The surface water alternatives are defined using the AP-III project proposal of phase I and phase II. Use is made of the priority ranking of water needs of villages (figure 4.1). This ranking is based on water scarcity classification, water quality, presence in a village of a PWSS or MWS schemes and water demand.

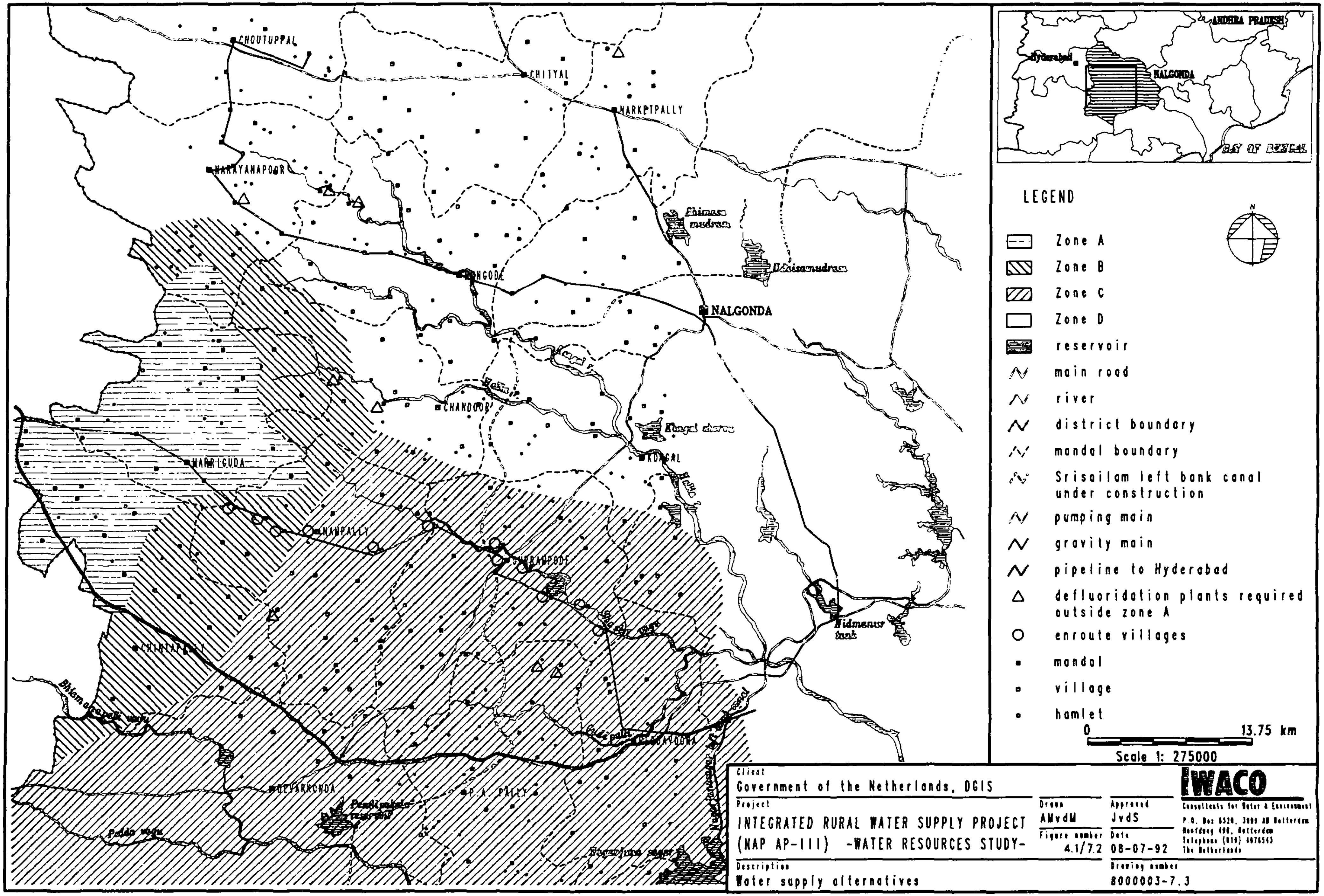
A design period of 30 years is adopted. Per capita supply is 55 liter per day (fluoride content < 1.5 mg/l). The following alternatives are discerned:

Surface water alternatives

- The original AP-III proposal (I-1)
- The modified AP-III proposal (I-2)

Groundwater alternatives

- Single village protected water supply schemes (II-1)
- Multiple village protected water supply schemes (II-2)


CHOUTUPPAL
CHITYAL
NARKETPALLY
NARAYANAPOOR
MUNGODE
NALGONDA
CHANDOOR
MARRIGUDA
KONGAL
NAMPALLY
GURRAMPODE
CHINTAPALLY
DEVARKONDA
P.A. PALLY
ANDHRA PRADESH
Hyderabad
NALGONDA
BAY OF BENGAL
LEGEND
Zone A
Zone B
Zone C
Zone D
reservoir
main road
river
district boundary
mandal boundary
Srisailam left bank canal under construction
pumping main
gravity main
pipeline to Hyderabad
defluoridation plants required outside zone A
enroute villages
mandal
village
hamlet
0
13.75 km
Scale 1: 275000
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Description
Water supply alternatives
Drawing number
8000003-7.3

Conjunctive surface groundwater alternatives

- Combination of original AP-III and groundwater (III-1)
- Groundwater and limited surface water in the west (III-3)
- Groundwater and supply from Hyderabad pipe line (III-5)

4.1 SURFACE WATER ALTERNATIVES (I)

4.1.1 Original AP-III proposal (I-1)

The original AP III surface water system is worked out in some detail in the project proposal. The project will be executed in two phases, phase I covering the northern part of the area (zone D in figure 4.1), phase two the southern part (zone A+B+C). The main characteristics of the project are:

- Source
Nagarjuna Sagar Left Bank canal with intakes at Nidanamur (phase I) and Awal (phase II) summer storage tanks at 33 km and 20 km from the project area respectively. The Awal tank needs to be improved. The canal supplies abundant water of good quality, fluoride content is 0.6 mg/l, no pesticides or micro pollutants have been detected in the canal nor in the storage tanks. Treatment includes rapid sand filtration and disinfection through chlorination.

- System lay out
The first phase with a design capacity of 259 l/s (22,400 m^3/day) covers 82 villages and 99 hamlets. The second phase has capacity of 298 l/s (25,800 m^3/day) and covers 144 villages and 238 hamlets. Pumping in four stages is required to reach part of the supply area. Maximum level difference to overcome is 230 m and the maximum distance from source to most distant village is 90 km.

- Environmental aspects
The environmental impact is minimal: quantities of water abstracted are small compared to the canal flow. This holds also for the sludge that will be brought back into the canal. There must be a slight positive effect on the groundwater balance in the area.

- Health and social aspects
Although small there is a risk that the source might get polluted or that the treatment is not properly working and a large area is infected as a consequence. High priority villages only be served in phase II of the project unfortunately. There are about 50 enroute villages that have to be incorporated in the scheme though not high in priority.

- Problems and risk
At least four pumps need to work more or less at the same time. Losses in the scheme might be considerable. The system might be hard to adjust to difference in growth and water demand over the area that can be expected over a 30 year period. The reliability of the source can decrease in summer time when water has to be taken from the storage tanks that are also used for irrigation. Conflicts of interest between the farmers and the Nalgonda town water supply system has already led to illegal tapping of the tankwater.

4.1.2 Modified AP-III proposal (I-2)

Following the recommendations of the Appraisal Mission the original lay out of the scheme was modified in such a way that 32 high priority villages worst affected by fluorosis in the south western part of the area are included in phase I (this area is depicted as zone A and B in figure 4.1). This will increase the production capacity of phase I to 347 l/s. Phase II production decreases to 180 l/s. All other aspects of the system remain similar to the original design.

4.2 GROUNDWATER ALTERNATIVES

4.2.1 Protected water supply schemes for single village (II-1)

- Source
  Combining the sources preliminary selected for each village(as discussed in section 3.3.3) about 550 wells are required to satisfy the demand in 2007 of 34,000 m³/day. This should be regarded as a maximum number as the well discharges adopted are conservative estimates and in case of doubt a welltype with the lowest discharge was selected. There will be villages where more problems will occur in finding a suitable source than expected, in others the revers might be true on a regional scale the picture will not be modified substantially.

  In 146 villages a system can be installed based on 1 or 2 wells. In 12 villages more than 6 wells are required up to 8 wells in Choutuppal, Appadjipet, Chillapur, Cherrugata, Chinakaparty, Nampally, Peddavura, Kurmaid, Marriguda, and Chepur. The distance source to village is less than 1500 m in 147 cases. For 35 villages it is unlikely that water of acceptable quality can be found within 2500 m. For these villages a defluoridation plant is proposed.

  If sources are well placed and not located inside villages water quality will remain safe. Although it is no current practise safety chlorination is provided. In some cases wells need to be protected by creating a water sanctuary. The dimensions of this zone around the well depend on the local situation varying from 50 to 200 m. In most cases this can probably be avoided by means of proper well construction and site selection.

- System layout
  No group schemes are considered. Water is pumped from the source directly in the (elevated) storage reservoir and will be transported by gravity to the supply area over an average distance per village of some 1,100 m.

  Power will be supplied by the Rural Electrification Corporation of India Ltd (REC). If the minimum period of 13 hours of 3 phase supply per day is not adequate single phase submersible pumps may be deployed. For most dug wells schemes the well storage is sufficient to attain the daily yield within 6 hours.

- Defluoridation plants
  35 defluoridation plants will be needed with a total capacity of 5,400 m³/day (63 l/s) in 2022. Individual plant capacity ranges from 40 m³/day to 320 m³/day to supply the full 55 lpcd. The Nalgonda technique using the fill and draw type will be applied according to the standard plants installed by the Technology Mission.

- Environmental aspects
  The groundwater abstractions have a negative effect on the groundwater balance in the area but abstraction amount to only a small percentage of present abstractions. In some areas water sanctuaries around wells need to be created that can be used for afforestation or less water consuming crops. In areas where water logging occurs (near tanks) lowering of the groundwater table will decrease evapotranspiration and hence salinization of soils. In these areas groundwater exploitation has a positive environmental effect.

  Serious consideration needs to be given to the disposal of sludge. Some 500 ton will annually be produced at full capacity . It should however not be too difficult to locate proper disposal sites or use the waste as construction material as the sludge is rather stable from a chemical point of view.

- Health and social aspects
  Sources will in general be located within the village administrative boundaries. This might not always be the case and problems might arise over water rights. The small scale of the systems makes this alternative more adopted to the village level and is in line with the trend to increase the involvement of the village population in the management of their own water resources

- Risks and problems
  The preliminary water resources assessment and source selection needs to be confirmed in the field. In some villages according to conservative estimates more than 6 wells are required. Detailed studies need to be carried out wether the number can be reduced. In those villages as an alternative still a defluoridation plant can be installed. The water supply systems should be carefully designed with due attention given to the location of the source. The hydrogeological wing of the PRED needs to be extended and reinforced as it is presently not well equipped to this task. There will be always a risk that certain wells will be influenced by private wells that cannot be controlled by any of the proposed measures and in the worst case a new well needs to be drilled.

  Although small there is a risk of deteriorating groundwater quality. Due consideration should be given to the implementation of wells in order to minimize this risk. In an individual case a source might have to be abandoned.

  In this alternative it is assumed that the implementation, operation and maintenance will be carried out by the PRED, additional institutional and organizational arrangements and reinforcement need to be successfully implemented. This holds for the hydrogeological wing of the PRED in particular.

4.2.2 Protected water supply schemes for groups of villages (II-2)

Whenever feasible protected water supply schemes are installed with a single distribution system for a group of villages.

- System lay out
  The villages that are most likely to be combined will be those that have high water production cost. Other group schemes can be made in areas where high yielding wells are found. Although not many of these areas exist several have been localised in the field near the dikes and the valley fills. Some surface water infiltration wells belong also to the potential sources for group schemes. The total number of schemes will reduce from 226 to at least 198.

- Defluoridation plants
  If possible defluoridation plants are avoided in favour of wells at some distance of the supply areas provided that better water quality can be found. In this way the number of plants can be reduced to 23. Centralised defluoridation plants to cut operation and maintenance cost and increase reliability. Assuming a plant capacity of 200 m³/day as optimal 12 plants can be reduced to 6 in the western hilly area.

- Risks and problems
  The sharing of water sources that will be necessary for the group schemes might cause problems. Involvement of the population in an early stage of the water system design including the selection of a suitable (and for all parties acceptable) well site might minimize problems of this kind. Other risks and problems will be similar to alternative II-1.

4.3 CONJUNCTIVE SURFACE GROUNDWATER ALTERNATIVES (III)

4.3.1 Combination of original AP-III and groundwater (III-1)

This alternative is a combination of groundwater alternative I-1, covering the area of phase 1 of the first surface water option and surface water in the phase 2 area (zone A+B+C in figure 4.1). The surface water source is the Awal tank. The surface water system production capacity is 282 l/s (2022) the groundwater contribution will then be 246 l/s.

The villages of highest priority are situated in the surface water area. Out of 33 villages with more than 4 wells, 17 are covered by the surface water.

4.3.2 Conjunctive option III-3

This alternative is based on groundwater alternative II-1 and a reduced version of the surface water alternative supplied by the Awal tank covering the fluoride villages in zone A (figure 4.1).

This zone comprises the villages with the highest priority ranking of water need and include the area where groundwater systems are expensive as defluoridation plants are needed. Water is pumped from the Awal tank following the design of the original phase 2. The production capacity in 2022 is 83 l/s including provisions for en route villages (15-20 l/s). In the remaining area still 8 defluoridation plants are required. Groundwater supply amounts to 455 l/s (2022 figures).

4.3.3 Conjunctive option III-5

The area that is covered by surface water from the Awal tank in the previous option will be supplied with 63 l/s from the Hyderabad water supply pipeline. This pipe line will not be completed before the year 2000.

The transmission main of the Hyderabad supply system will follow the road from Nagarjuna Sagar via Chintapally and Mal (utmost western part of the study area and highest elevated village) to the town. From Mal the water can be supplied under gravity to the area.

5. PRELIMINARY FINANCIAL ANALYSIS OF SUPPLY ALTERNATIVES

The cost of the original proposal of the AP-III surface water scheme has been estimated in the project documents. The cost of surface water components of the other alternatives have been derived from this estimate. For the groundwater components a model has been developed that estimates the cost of individual water supply systems for each village. The results have been used to estimate the groundwater alternatives and the groundwater components of the conjunctive use systems.

The cost of the alternatives have further been converted to net present cost per m³ sold in order to make the different estimates compatible and to select the least-cost alternative. The results are briefly discussed here and presented in table 5.1. It can be seen that the production capacity of the first surface water alternative is slightly less than that in the original AP-III proposal (528 l/s instead of 558 l/s). A correction had to be made to adjust for the lower population projections that where based on the 1991 census results. All other assumptions have been according to the original PRED proposal.

5.1 SURFACE WATER ALTERNATIVES

Using the PRED design of the original project and applying the unit prices for different system components a preliminary cost estimate has been made of the modified option. If necessary system components have been adjusted to allow for the new dimensions like pipe diameters, reservoirs, pumps and distribution systems. Furthermore it was assumed that the total cost of the system remains the same.

5.2 GROUNDWATER ALTERNATIVES

In order to have a first estimate of the cost of alternatives that are (partly) based on groundwater an economical model has been developed. With design criteria and unit rates according to the PRED and with similar assumptions as used in the estimates of the surface water system, the model computes design parameters and specific cost calculations for a given set of input data. It can be used for a groundwater system for an individual village or for a group of villages. It has been applied for each village following the preliminary source selection discussed in section 3.3.3.

The model determines the main design parameters of a groundwater system for a given (hydrogeological) situation and water demand, in terms of pipe diameters, pumping heads, power supply and chemical requirements. It can be used to calculate the present costs of investments and operation and maintenance of water production, transmission and treatment units. Unit rates and results of the model are presented in Volume II.

Table 5.1: Summary of water supply alternatives and cost per m^3

			2007				2022			
			Costs per m^3				Costs per m^3			
Alternative	Discussion	Phase	Capacity l/s)	Investment	Operation and maintenance	Total	Capacity l/s	Investment	Operation and maintenance	Total
I-1	Original AP-III proposal	phase 1	185	7.73	2.96	10.68	246	9.82	2.96	12.78
		phase 2	212				282			
I-2	Modified AP-III proposal	phase 1	261	8.19	2.98	11.15	347	9.43	2.98	12.41
		phase 2	136				181			
II-1	Protected water supply schemes for single village	226 systems	397	8.88	1.89	10.77	528	9.89	1.89	11.78
II-2	Protected water supply schemes for group of villages	198 systems	397	8.43	1.70	10.13	528	9.39	1.70	11.09
III-1	Combination I-1 and II-1	surface water	212	8.44	2.38	10.82	282	10.60	2.36	12.96
		ground-water	185				246			
III-3	Combination II-1 and reduced surface water from Awal-tank	surface water	62				83			
		ground-water 187 systems	335	11.32	2.55	13.88	445	10.47	1.91	12.38
III-5	Combination of II-1 and reduced surface water from Hyderabad	surface water	47				63			
		ground-water 199 systems	350	11.06	3.12	14.18	465	10.36	2.03	12.39

5.3 CONJUNCTIVE SURFACE GROUNDWATER ALTERNATIVES

In the conjunctive alternative III-1, the same figures are used as the original AP-III surface water phase 2 estimates. The cost of groundwater is the total of the individual systems in the phase 1 area as in groundwater alternative II-1.

In alternative III-3 the phase 2 design and unit prices from PRED an estimation is made of the cost involved. Where necessary design of system elements have been adjusted to new capacity. For the groundwater system the cost have been estimated similar to II-1.

For the cost estimates in alternative III-5 it is assumed that water has to be bought from the Hyderabad Metropolitan Water Works at the maximum rate 7 Rs/m^3. Costs of the distribution system are estimated applying again PRED standard figures and design assumptions. The groundwater part is as III-3.

5.4 NET PRESENT COST PER M³

A financial analysis has been carried out to have a first estimate of the least cost alternative using the net present cost (of instruments and operation/maintenance) per m³ as a measure. Due to lack of data and the number of assumptions that had to be made this estimate can only be a preliminary one. The following assumptions have been made:

Investment
Investments are differentiated into two types of investments:

1 Initial investments
These investments are made at the start of the project. It is assumed that for all options, the first phase of investment will start in 1992 and be finished in 1995. The second phase of the project will cover the period 1995 to 1998. One exception is the conjunctive surface and groundwater alternative III-3 and III-5 which - due to the scale of the system - is assumed to start and finish construction in 1995.

2 Replacement investments
During the time horizon of the project which is set at 30 years, replacement investments will be needed. The lifetime for electro-mechanical equipment and pumps is set at 10 year. During the time horizon of the project this equipment will have to be replaced twice. It is assumed that for all alternatives, except for surface water, the replacement costs are equal to 25% of the initial investment costs.

Operation and maintenance cost
The operation and maintenance costs consist of raw water costs, energy, chemicals, manpower and maintenance. The operation and maintenance costs for the surface water option are set at Rs. 52 million per year. For the groundwater option, the operation and maintenance costs are estimated by the model at Rs. 31.4 million per year. The alternatives which combine the two options of surface and groundwater are based upon the assumption that the operation and maintenance costs vary proportionally with the volume sold.

Discount rate
For the analysis a discount rate of 10% has been used.

The results for the design horizon 2007 and 2022 are presented in table 5.1.

6. ANALYSIS OF SUPPLY ALTERNATIVES

6.1 INTRODUCTION

The 7 alternatives that are selected have been evaluated using a multicriteria decision analysis. It is helpful tool for the weighing of advantages and disadvantages of each alternative. It has been used to come to a preliminary selection of an optimal alternative.

The mathematical scheme selected for the aggregation and evaluation of the indicators and of system performance is called composite programming (UNESCO 1988). The use of the composite programming methodology begins with the selection of basic indicators to represent the system being analyzed. These basic indicators can be combined to a limited set of evaluation criteria. As evaluation criteria were taken:

- Total investments
- Operation and maintenance costs
- Reliability of supply
- Coverage of priority needs
- Investigation requirements
- Environmental impact
- Community involvement

The first two evaluation criteria have been discussed in the previous chapter. The other criteria will be explained in the following section.

6.2 EVALUATION CRITERIA

6.2.1 Reliability of supply

The reliability of supply is defined as the ability of a system to supply water of sufficient quantity at all times. It depends on technical and hydrological aspects. In case of groundwater systems the reliability is more determined by hydrogeological factors than by mere technical ones. The technical (un)certainties are more or less equal for all the villages, except for the schemes with defluoridation plants. For individual groundwater systems the reliability of supply is expressed as a combination of the following indicators:

- type of wells
- number of wells
- hydrogeological zone
- stage of groundwater development.

For the surface water system the reliability of supply in a particular village is more determined by technical aspects (the hydrological factors being the same for the area as a whole). The reliability is expressed as a function of the following basic indicators:

- pipe line distance from supply area to the source (intake)
- elevation difference between intake and supply area
- number of pumping stages to the supply area

In order to compare the reliability of a surface water system to a groundwater system a pair wise comparison weighing procedure has been adopted. For each alternative the reliability scores of individual villages are weighed according to village population and summed to obtain the reliability of the alternative.

6.2.2 Coverage of priority needs

The alternatives are being evaluated for the extent and the moment in which the villages with the highest priority ranking are being covered. The score for the coverage of priority needs will be lower in the original AP-III proposal, that cover most of the priority villages in the second implementation phase, than for the groundwater option where the most urgent villages can be covered at the beginning of the implementation.

6.2.3 Investigation requirements

The groundwater assessment carried out indicated that at a regional scale sufficient water is available, at a local scale problems might arise concerning water quality and water quantity. There will be villages where locating acceptable sources will be more problematic than in other villages. The criteria will give a measure of success in locating borewells of the expected type, discharge and distance. The present village water availability assessment can only be verified by drilling wells. For surface water no such incertainty exists as the source is visibly present. The need for further investigations increases as the component of groundwater increases.

6.2.4 Environmental impact

Although the overall environmental impact is overall low for all the alternatives, the production of fluoride rich sludge can not be neglected.
The environmental impact has been considered but is not taken as a criteria as overall impact is small and differences among the alternatives are assumed to be marginal. In fact, negative impact increases with the number of defluoridation plants required in an alternative.

6.2.5 Community involvement

This criteria reflects the extent of community involvement required and/or possible. A high level of community participation can be seen as an advantage or as a disadvantage. It will be clear that in the groundwater alternatives a higher participation of the community is required than in the surface water alternatives. The village community should be involved in selecting suitable well sites and eventually donate land etc.. They eventually can play an active role in the management and operation of the system. This in turn might it make possible for the PRED to transfer some of their operational tasks to the village. Although it has not received an important weight in the analysis, it is a criteria worth considering as the project as a whole is a rural development project in which the self reliance of the population is one of the objectives.

6.3 RESULTS OF THE ANALYSIS

In table 6.1 the values of each of the indicators for the situation 2022 are presented. Table 6.2 shows the results of the analysis for different weights of the indicators.

Table 6.1: Indicator values

Alternatives	INDICATORS						
	Investments 2022	Operation and Maintenance 2022	Priority coverage	Reliability of supply	Investigation requirements	Environmental impact	Community involvement
I-1	9.82	2.96	0.05	0.074	0.05	0.18	0.04
I-2	9.43	2.98	0.08	0.075	0.05	0.18	0.03
II-1	9.89	1.89	0.27	0.129	0.23	0.11	0.24
II-2	9.39	1.70	0.27	0.132	0.23	0.11	0.28
III-1	10.60	2.36	0.11	0.096	0.10	0.15	0.08
III-3	10.47	1.91	0.13	0.122	0.16	0.14	0.12
III-5	10.36	2.03	0.09	0.141	0.18	0.13	0.21
best value	9.39	1.70	0.27	0.141	0.05	0.18	0.28
worst value	10.60	2.98	0.05	0.074	0.23	0.11	0.03

Table 6.2: Weight of criteria and score of alternatives

Criteria	WEIGHTAGE SCHEMES				
	1	2	3	4	5
Investment	0.05	0.14	0.10	0.11	0.24
Operation and Maintenance	0.26	0.14	0.31	0.26	0.24
Reliability of supply	0.32	0.14	0.01	0.43	0.01
Coverage of priority	0.10	0.14	0.16	0.01	0.01
Investigation requirements	0.17	0.14	0.21	0.18	0.24
Environmental impact	0.04	0.14	0.09	0.01	0.24
Community involvement	0.07	0.14	0.12	0.01	0.01
ALTERNATIVES					
I-1	0.34 (7)	0.39 (6)	0.37 (7)	0.26 (7)	0.65 (2)
I-2	0.36 (6)	0.44 (5)	0.42 (6)	0.29 (6)	0.72 (1)
II-1	0.59 (3)	0.59 (2)	0.59 (2)	0.67 (3)	0.38 (7)
II-2	0.65 (1)	0.69 (1)	0.70 (1)	0.75 (1)	0.51 (3)
III-1	0.48 (5)	0.38 (7)	0.43 (5)	0.45 (5)	0.44 (5)
III-3	0.56 (4)	0.46 (4)	0.50 (3)	0.61 (4)	0.45 (4)
III-5	0.60 (2)	0.49 (3)	0.46 (4)	0.70 (2)	0.38 (6)

(1) ranking

An essential part to interpret the results is the weight that have been attributed to each of the evaluation criteria. The weights are determined by pair wise comparison and are given in table 6.2 in column 1. A sensItivity analysis was carried out in order to get a clearer understanding of which indicators and the weights assigned to them, most influence the final results. Some of the results of the analysis for different weights are shown in the same table. The results for the horizon 2007 are not shown as they do not differ substantially from the 2022 horizon.

It can be seen from the table that the groundwater alternative II-2 ranks highest in the first weight scheme. The weights assigned to each of the indicators is obtained from a careful evaluation of the indicators by pair wise comparison by several water supply experts. The investments are considered of limited importance in the case of the project compared to the other indicators as operation and maintenance cost or reliability of supply. As can be seen from the table 6.1 the investment costs of the alternatives do not vary much. The alternatives II-2 (groundwater group schemes) is clearly to be preferred over II-1 (single village PWSS systems) Changing the weight factors cause only some minor changes in the score but does not change the ranking. In weight scheme 2 all factors are set equal. In scheme 3 the reliability of supply (that is in favour of the groundwater options) is considered equal for all alternatives and is set at 0.01. The end result is not modified.

In scheme 4 the weights of the 'soft' indicators such as coverage of priority needs, community involvement and environmental impact are not considered important and set at 0.01 in order to have a more technical and economical evaluation. The gap between surface water and groundwater alternatives remains the same. Only if the reliability criteria, the coverage of priority and the community involvement indicators are not considered (weightage scheme 5) the surface water alternative ranks first.
The alternative III-5 (Hyderabad pipeline supply) ranks second in weighting schemes 1 and 4 and ranks third or four in others. This despite the high operation and maintenance cost and a low priority coverage (see table 6.1). If the operation and maintenance cost appear to be lower than assumed it might rank first. This depends for an important part on the price per m^3 that has to be paid to the Hyderabad Metropolitan Water works.

7. CONCLUSIONS AND RECOMMENDATIONS

Prospects for developing groundwater resources for drinking water supply are good. It is a realistic alternative that deserves to be considered in more detail.

The groundwater alternative with Protected Water Supply Schemes that supplies more than one village and with boreholes at a distance to avoid defluoridation plants where possible, has additional benefits over the alternative that consists of single village supply schemes only.

The evaluation criteria, 'reliability of supply' may be disputed. According to experts the reliability of the sum of individual groundwater systems is higher than one regional surface water scheme. Even if the reliability indicator is not considered in the multi-criteria analysis groundwater alternatives rank substantial higher. In case this criteria needs to be defined with more precision it is recommended to evaluate the reliability of existing surface water schemes in Andhra Pradesh.

The investment cost of the studied alternatives do not differ significantly. Highest and lowest values are within 12% of each other. Operation and maintenance costs differ as much as 75%. An important weight is assigned to these costs in the analysis. There is still some uncertainty about these operation and maintenance costs. For the surface water alternative an estimate has been used that should be specified in more detail. The same holds for the groundwater alternative where there is a general feeling that these costs have been estimated too high.

From the analysis of alternative III-5, in which part of the area is supplied by water from the Hyderabad pipeline, seems an attractive option as it means a reliable supply for that part of the study area that is worst affected by fluorosis. It is recommended to study this alternative more closely. The real cost per m^3 that has to be paid to the Hyderabad Metro Water Supply and Sewerage Board, the completion date of the project and the maximum capacity that eventually can be supplied should be known before a final evaluation of this alternative.