Government of Bangladesh
Ministry of Local Government
Rural Development and Cooperatives
Department of Public Health Engineering

Government of the Netherlands
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Directorate General of
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NETHERLANDS-BANGLADESH DEVELOPMENT CO-OPERATION PROGRAMME
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Operational Flexibility in Water Supply Systems 18DTP

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1 INTRODUCTION

In water supply systems flexibility is needed to match supply to fluctuating demand conditions. Demand may vary for a number of reasons:

* The demand will fluctuate with requirements at different times of the day.
* The demand may fluctuate with seasonal needs.
* The number of consumers will vary in time, and the design demand may only be achieved after some time
* Leakage and wastage may increase or decrease over time.

  If no flexibility is provided in a water supply system, pressures will fluctuate dramatically. If actual demand structurally exceeds design demand (and supply capacity!), low pressures may occur.

In 18DTP, system flexibility has due attention. This paper tries to discuss system flexibility in 18DTP, and evaluate various options to increase flexibility.

2 PROBLEM FORMULATION

In water supply systems demand fluctuates in time. On the other hand, production of clean water from a source is kept as constant as possible for cost efficiency. To match these two potential conflicting parameters, some flexibility needs to be built in the system.

3 FACTORS AND CRITERIA

For fluctuating supply-demand conditions, and for flexibility measures to solve the discrepancy, various factors are of importance:

* Accuracy of consumption prognosis. With better prognosis and system design, the (unforeseen)requirements on flexibility may be lower.
* Accuracy of demand factors like leakage, wastage, peak factor, non domestic demand. Again with better prognosis the (unforeseen) requirement on flexibility may be less.
* Phasing of implementation with demand increase. With better phasing, initially required flexibility may be less.

Any options for achieving flexibility may be compared on the following criteria:

* Flexibility to meet varying conditions.
* Cost, both investment and operational costs.
* Impact of unforeseen conditions (for instance overexploitation of direct pumped production wells results in accelerated clogging of screens).
* Technical system sustainability.
* Familiarity with, and appropriateness to Bangladesh conditions.

4 EXISTING APPROACH AND BACKGROUND

In 18DTP the need to include storage in water supply systems was initially foreseen. As raised storage (OHT, OverHead Tank) was considered expensive, inflexible because of fixed level, and liable to malfunctioning through 'by passing', ground level storage was proposed. The ground reservoir would be supplied from a number of production wells. The distribution system would be supplied from the reservoir through a booster pump station, with a ranging pump capacity to meet fluctuating demand. During non supply night hours the system would be fed, by gravity, from the reservoir, to keep the system at minimal pressure to prevent intrusion of surrounding polluted water into the (leaking) pipes.
For budgetary reasons, and because sustainability was questioned, the proposed lay out was abandoned. Now, 18DTP implements direct supply in (nearly) all systems. Flexibility is intended by spare supply capacity which may be operated under unforeseen peak demand conditions, or breakdown of one of the wells. As far as 18DTP implementation concerns, the commitments for Batch-I only partly realize this intention for spare capacity. For Batch-II virtually no spare capacity is included in the commitments.

In this respect it is relevant to assess the prognosis of peak demand conditions. In Bangladesh investigations on current consumption patterns are (very) limited. Water meters have not yet been installed in 18DTP (action is now taken). In 12 DTP a few bulk meters were installed in 3 towns only (domestic meters in 1 town only), and data could be used for 18DTP (action has been taken on Munshiganj data). It is fair to say that design criteria for 18DTP are to some extent assumptious and based on international 'averages'. Some study on leakage and wastage in Bangladesh was made outside the scope of 18DTP, finding water losses in the range of 45 to 70%. In the earlier Khulna project it was found that, after a sudden and drastic improvement in service level, per capita demand amounted to more than 200 lpcd in metered, and to more than 300 lpcd in unmetered connections. This is in sharp contrast to the 75 lpcd as assumed in the Khulna design. The 18DTP criteria on consumption, peak factor (1.2), leakage and wastage (20%), do not reflect existing conditions, and there should at least be some doubt as to their accurateness on foreseen conditions.

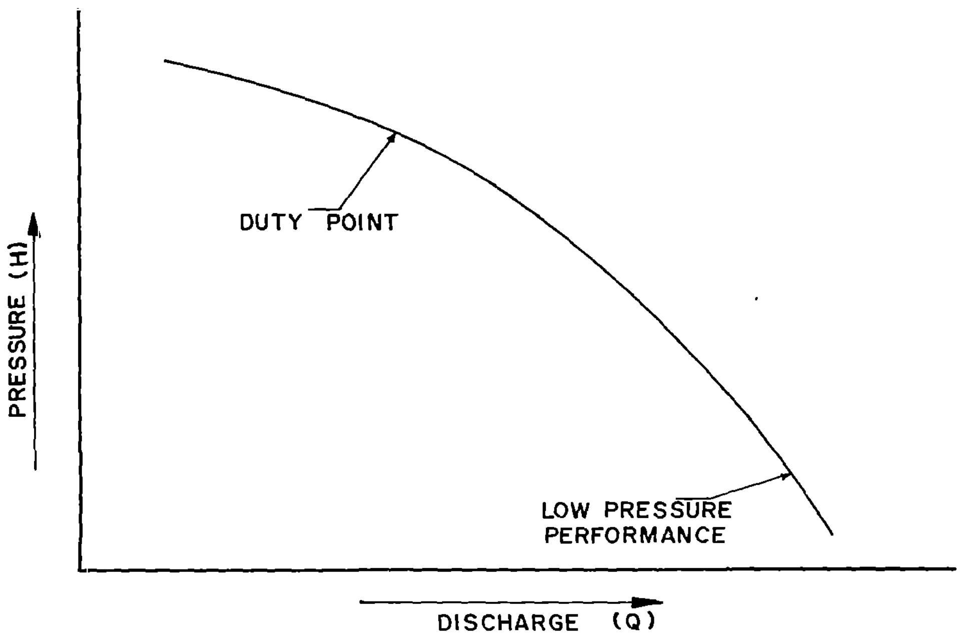
5 OPTIONS FOR ACHIEVING SUPPLY FLEXIBILITY IN 18DTP

In this chapter various options for achieving system flexibility in 18DTP systems are discussed.

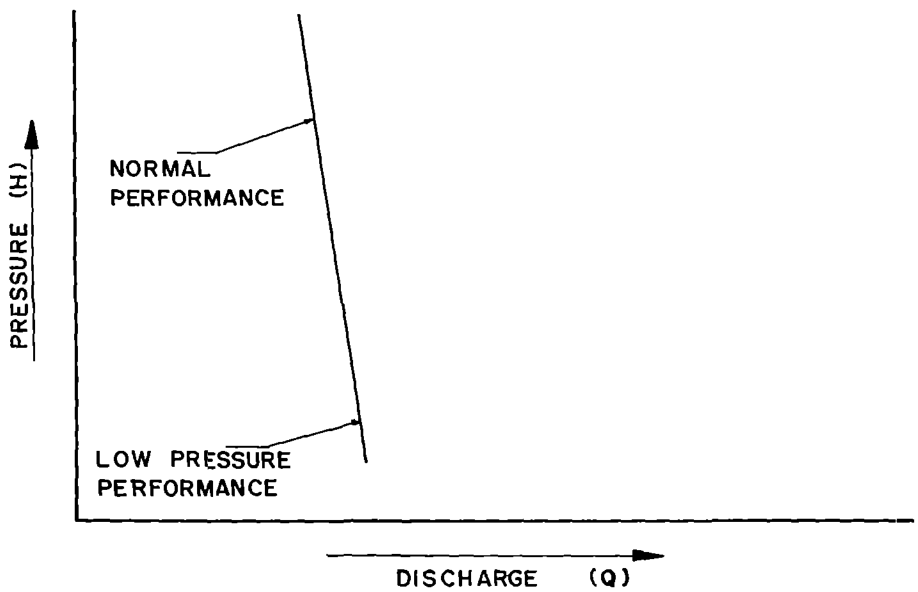
5.1 System Operation with Monopumps

Currently nearly all production wells in Bangladesh are operated with centrifugal borehole pumps (with the motor mounted at groundlevel). These pumps have a curve of pressure-discharge relations (Q-H Curve). A feature of these centrifugal pumps is that when

TYPICAL PERFORMANCE CURVE OF CENTRIFUGAL PUMP



TYPICAL PERFORMANCE CURVE OF MONO PUMP



demand increases, and system pressure is reduced, the discharge from these pumps increases dramatically. In practice this often results in the borehole being overexploited (discharges being double the 'safe yield' of the borehole are not uncommon). Monopumps have quite different pressure-discharge curves. Actually over a wide pressure range the difference in discharge is very small. Therefor, by using monopumps the boreholes may effectively be protected from exploitation far beyond the designed safe yield.
Although the advantage of monopumps, as discussed above, is acknowledged, monopumps will not be proposed in 18DTP for the following reasons:

* Monopumps are completely new to Bangladesh water supply. Serious problems in procurement, operation, and maintenance (availability of spare parts, know how of mechanics) are foreseen.
* With centrifugal pumps an unintended flexibility is included for unforeseen demand conditions. With lower pressure an increased supply is achieved, although it is at the cost of borehole lifetime. With monopumps this flexibility does not exist. Flexibility can only be achieved by installation of extra production wells and keeping these extra production wells operational. Problems in system performance are foreseen.
* While mono pumps are not manufactured in Bangladesh, various pump suppliers have been addressed in the Netherlands. With these suppliers application of monopumps in boreholes is considered most uncommon, and not within their range of supply. It is not recommended to introduce this (uncommon) technology in Bangladesh.
* The following unfavourable features of monopumps are mentioned by suppliers:
  # excessive space requirement (difficult in borehole)
  # relatively sensitive to 'dry pumping' (serious risks in case draw down in borehole is excessive)
  # very expensive
  # not available for the required discharges

5.2 Groundlevel Storage

For 18DTP groundlevel storage has long been the proposed solution to meet the required system flexibility. A number of production wells may supply into the reservoir. From the reservoir the system is supplied through a pump station. Features of this option are:
* Cost of a ground reservoir is lower compared to an OHT. However, savings are limited as foundation is on piles. Moreover the combination of a groundlevel reservoir with booster station may only create minor cost savings, if any.
* Operating costs of the two stage pump system are higher than direct pumping, or a system with an OHT (with only one stage pump).
* Systems with groundlevel storage are new to Bangladesh. Some earlier efforts in this direction failed with groundlevel reservoirs remaining unused (Pabna, Kustia and many others). It is feared that without a strong training input groundlevel reservoirs may soon be by passed to save electricity costs by avoiding the second pump stage.
  It may be advisable to implement groundlevel storage without the physical possibility to by pass the reservoir. This, however, makes the system less flexible: In case the

booster pumps break down, direct supply from the sources is physically impossible.
* The 1988 review mission proposed generator sets 'if necessary'. It is difficult to assess that need. Power failures are very common (usually daily) in 18DTP towns. Currently this is felt to be quite acceptable, but with proposed improvements we may wish not to accept this. If generator sets are proposed, the whole groundlevel option becomes more liable to troubles in operation and maintenance, and investment costs increase significantly.

5.3 Raised Level Storage

With raised level storage, a number of production wells supply water to the OHT (OverHead Tank). From the reservoir water is supplied into the distribution system. Periods of pumping and supplying of water do not necessarily coincide. Apart from supply from the reservoir, supply may be augmented from production wells directly connected to the system.
Features of this option are:
* The system is quite flexible to varying supply-demand scenarios, but the fixed level limits opportunities to change pressure range in future (however, as with groundlevel storage, a booster station could introduce that flexibility).
* Investment costs are rather high. If operated correctly, the system is robust with low running costs.
* The system is liable to malfunctioning through by passing. It is suggested to physically exclude the possibility of by passing.
* The system is 'power cut proof' for short power failures.
* The system is familiar to Bangladesh.

5.4 Extra Production Capacity

A service level can be maintained, and boreholes can be protected, by providing extra production capacity for peak demand periods. For this approach to be successful, a good assessment of 'peak demand' is required. This option is currently implemented by 18DTP. If current conditions do not change dramatically, the peak demand may be grossly underestimated by 18DTP. While it is appreciated to keep targets ambitious, it is considered prudent to evaluate proposed systems on worst case conditions. While providing extra production capacity may be quite viable to achieve flexibility, it is felt that 18DTP should provide quite some more extra production capacity if this flexibility is to be achieved.
Features of this option:
* Provision of extra capacity strongly depends on proper assessment of peak demand.
* If peak demand is underestimated, or if production capacity declines (wells out of operation, 3 hours supply instead of >12 hours supply) the situation may deteriorate.
* Investment costs are relatively low (while it is inefficient to develop the full system on peak demand, it proves to be relatively inexpensive).
* Running costs are relatively high, particularly when keeping in mind the maintenance

of extra pumps and potential well regenerations.

* By scattered location of wells extra system flexibility is achieved (at the cost of some extra operation).

6 DISCUSSION

	Flexibility	Invest. cost	Oper. cost	Impact excessive demand	Sustainability	Appropriateness to Bangladesh	Reliability /Full Proof	Over all
Monopumps	--	+/-?	--	--	--	--	--	--
Ground storage	+	-	+/-	+	+/-	-	-	+/-
Elev. storage	++	-	+	++	+	+	++	+
Extra wells	+/-	+	-	-	+/-	++	+/-	+/-

In the comparative table the findings of the previous chapter are summarized. It is recommended not to consider monopumps in 18DTP. It is further recommended to compare an OHT with extra wells. The comparison should concentrate on costs and operational performance.
For better understanding of the application of an OHT in the systems two case studies have been conducted. In the network computer model the Netrakona system has been simulated with and without an OHT. It is found that the pressure distribution is much better with an OHT, especially if demand (leakage/wastage) is excessive.
In Munshiganj different supply scenarios (with and without OHT) were compared on system pressure. It was found that system pressures with OHT are higher, especially if supply is combined with pumps around the system. It was further found that fringe areas, away from OHT or pump, experience low pressure under all scenarios.

7 COST ANALYSIS

For comparison between an OHT and extra wells investment costs are an important parameter.
For extra production works (borehole, test tubewell, and pump house) investment costs are strongly dependant on local conditions.
For production works investment may be characterized as follows:

Shallow borehole: Tk 800,000 to Tk 1,400,000

Deep borehole : up to Tk 2,000,000

For the OHT required investment will be roughly the same in the different towns:

Standard 400 m3 reservoir (top level 22 m): Tk 3,500,000

It can be seen that investment comparison may be quite different for different towns.

Towns with shallow aquifers may opt for extra production capacity, especially if additional capacity per well is large. Towns with deep aquifers may opt for an OHT, especially where capacity per well is constrained.
As for operation and maintenance, no detailed assessment of costs was made yet. The maintenance, and potential regenerations of extra pump houses are costly. Maintenance of OHT's is more easily neglected, but after a number of years costs may be quite high.

N.B. For Jhalakati a ground reservoir with booster station was initially proposed at a cost of Tk 3,400,000. The cost saving in investment compared to an OHT is only marginal. Operational costs for ground storage with booster station will be significantly higher.

8 CONCLUSIONS AND RECOMMENDATIONS

* Under Bangladesh water supply conditions with, to a certain extent, unpredictable demand, flexibility to match supply and demand is crucial to efficient operation.

* The recommended solution for achieving system flexibility depends on town specific conditions. In places where groundwater is shallow, and capacity per production well is high, it is most appropriate (economic) to achieve flexibility through spare capacity, despite the consequence of extra operation & maintenance required with extra wells. In places where groundwater is deep, and capacity per production well is low, it is most appropriate to achieve flexibility through application of an OverHead Tank. In those cases production capacity should be divided between OHT production wells, and remaining wells distributed over the system.

* Monopumps are unknown to Bangladesh, generally inappropriate for application in boreholes, and quite ineffective in achieving system flexibility. Monopumps should not be used in Bangladesh water supply.

* Ground storage is technically quite effective to provide a buffer storage in a water supply system. However, because of the booster station required, investment costs are only slightly favourable compared to an OHT. Operation & maintenance requirements are high. The system is quite vulnerable to malfunctioning through by passing of the reservoir, thus avoiding operation of the booster station.

* Regardless of system lay out and solutions to flexibility requirements, it must be realized that leakage and wastage pose a tremendous problem to water supply systems in Bangladesh. Efforts on reducing leakage and wastage are of paramount importance.

It is recommended to review 18DTP production policy. The specific towns where either extra production capacity or construction of an OHT are proposed should be identified. Specific system designs will need to be finetuned accordingly, and budget allocations will need to be reviewed.

ANNEX 1 NETRAKONA CASE STUDY

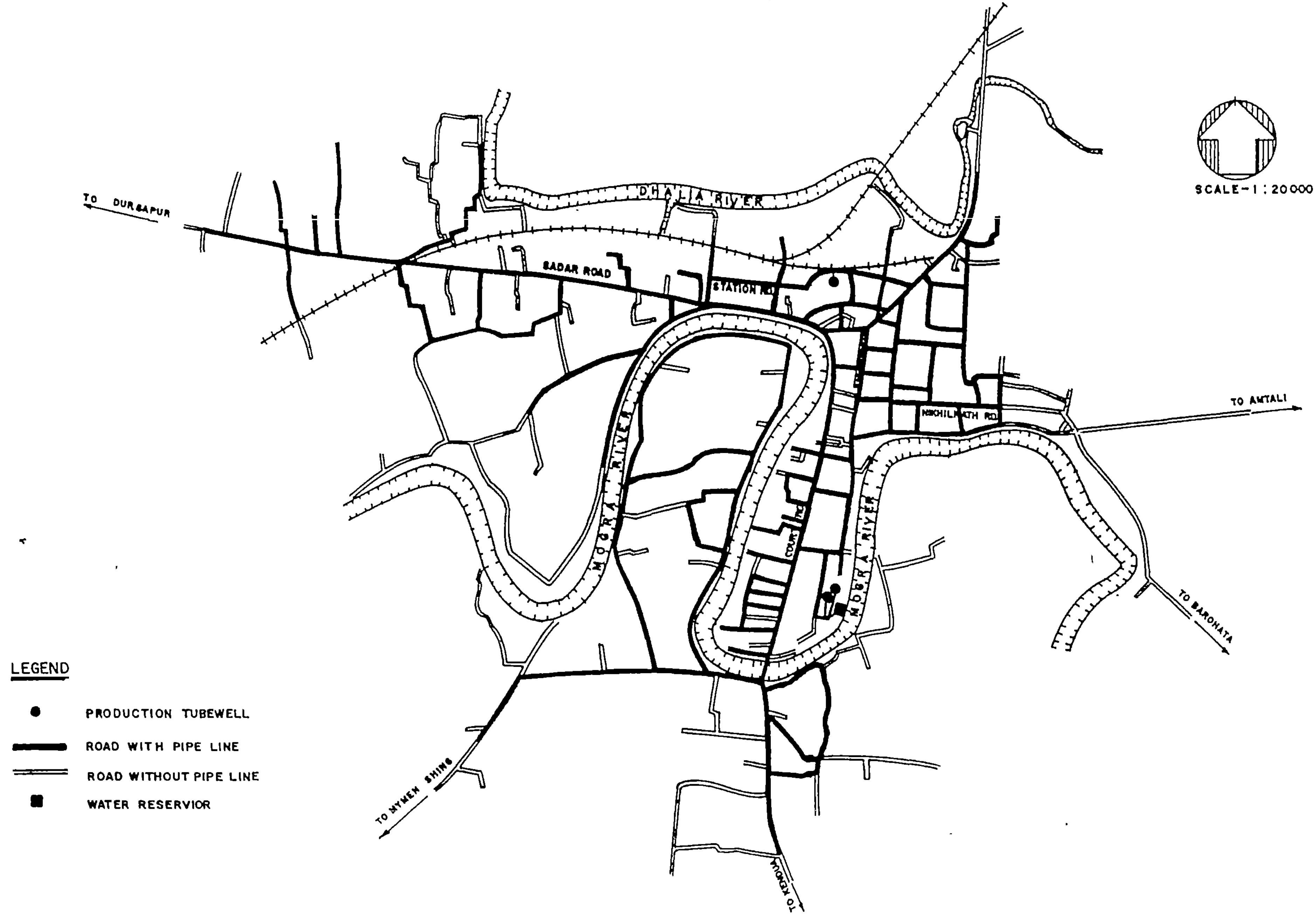
To evaluate the impact of various design aspects, Netrakona water supply system is used as a case study. For this purpose data of option 2 of the 'Netrakona Feasibility Study' have been used.
The average hourly production is stated as 247 m3/hr. In option 2 calculations in the same report, 355 m3/hr is used and the network was designed accordingly. However, in our case study 247 m3/hr is considered the average hourly production.

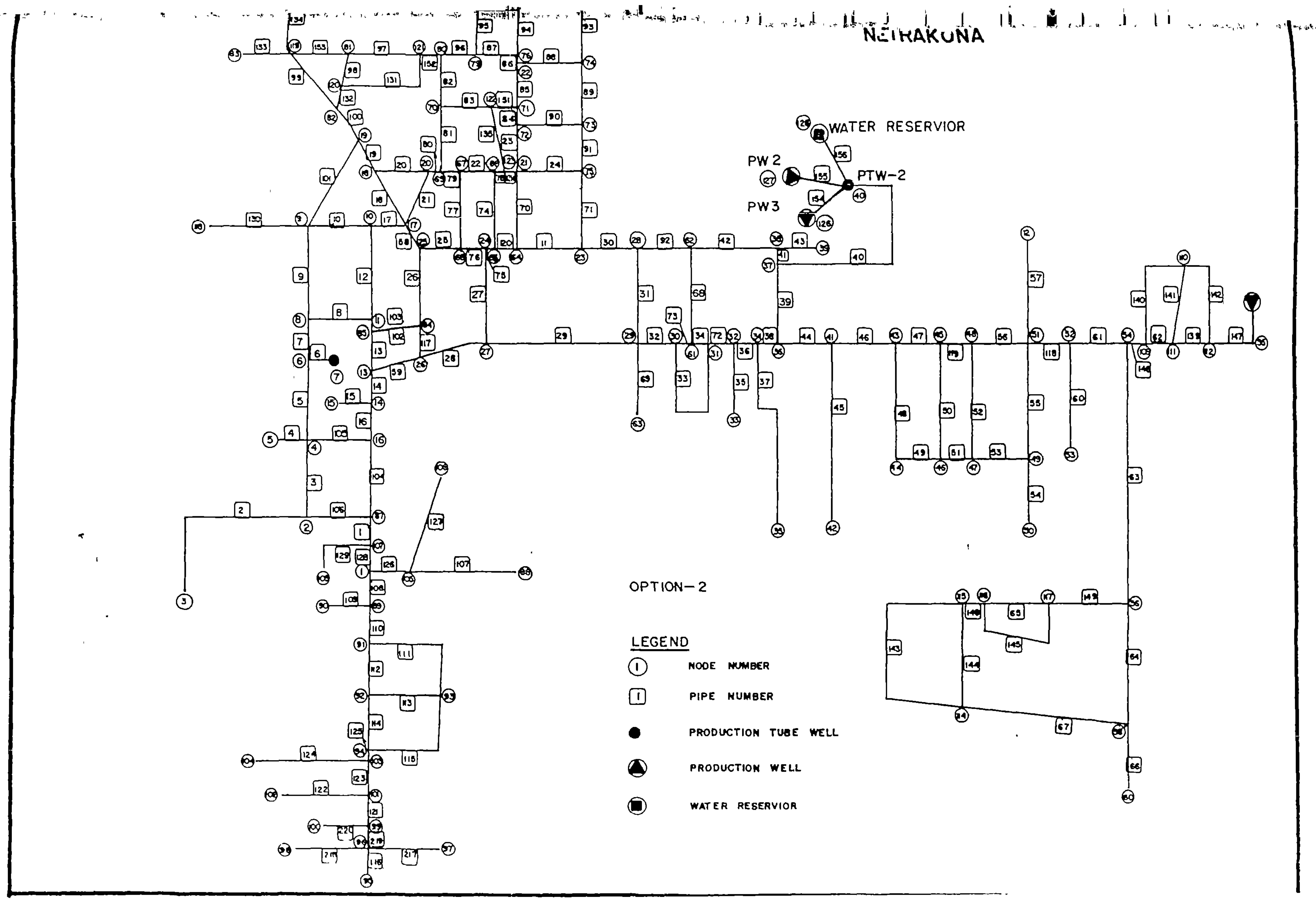
For Netrakona two different lay outs are compared. In one lay out production is achieved with 4 production tubewells at three locations. These tubewells supply directly to the distribution system. In the other lay out two of the production tubewells supply directly to the system, while two production tubewells supply via an OHT with a level of 22 m.

When the two lay outs are compared during normal, 'expected' operation, both can be considered satisfactory. If demand exceeds to a level of 1.6 times the 'expected' demand, pressures in lay out 1 drop to levels below 5 m, while lay out two maintains an overall pressure of more than 15 m. Furthermore the tubewells in lay out 1 are excessively overexploited.

In this case (as in most cases in Bangladesh) the distribution system is dimensioned rather large for the 'expected' flows. This results in still acceptable flow conditions when rather excessive flows occur. Under these conditions the supply capacity is the limiting factor, rather than the distribution capacity.
In the lay out with direct supply from boreholes only, the flexibility is limited as the pumps are only capable in certain discharge capacity ranges. At the same time, direct supply will lead to overexploitation of boreholes as and when excessive demand occurs. With direct supply, flexibility can only be achieved by introducing extra production wells. With these extra production wells operational management will be required to keep the right number of wells running in accordance to demand conditions.
When an OHT is included in the system, it will enhance flexible supply-demand conditions. As the distribution system is quite capable to handle excessive flows, the supply from the OHT will simply increase with demand. This means that a better pressure is maintained over the system, giving a better performance from the remaining, direct supply, production wells. It should be realized however, that with an improved pressure distribution leakage and wastage may increase accordingly (higher pressure means higher loss if leaks remain equal). With higher pressure, leakage and wastage may become more apparent, and it is of paramount importance that a proper leakage and wastage control is enforced.

FIG. B·15 FUTURE PIPED WATER SUPPLY SYSTEM OPTION - 2, NETRAKONA




NETRAKONA
WATER RESERVIOR
PW 2
PTW-2
PW3
OPTION-2
LEGEND
NODE NUMBER
PIPE NUMBER
PRODUCTION TUBE WELL
PRODUCTION WELL
WATER RESERVIOR

ANNEX 2 TEST OHT PERFORMANCE IN MUNSHIGANJ

Issue: Low pressures have been noted in water supply systems in Bangladesh towns. It is found that due to excessive demand (due to leakage and wastage) supply from pump houses increases, with, as a consequence, dramatic pressure drops. From models it is predicted that, given a reasonably oversized distribution system, with the large supply capacity of an OHT a far improved pressure distribution can be maintained. A field trip was made to Munshiganj to verify this prediction, and to test to what extend the application of an OHT can be termed successful in achieving an improved pressure distribution in the context of a 'typical' Bangladesh town.

Methodology: Segments of the water supply system have been supplied alternately by pumps, OHT, or a combination. Flows and pressures have been monitored.

Programme: Munshiganj Pressure Distribution Test
Date: Monday 25 January

The Munshiganj system is divided in 3 zones, A, B, and C (see fig 1). Zone C was excluded (isolated) from the test. Zone A has been the focal point of the test, while by alternately excluding or including zone B, the supply coverage was varied. In zone A 6 pressure meters (1-5, 7) were placed, while pressures were further recorded at PW 4 and PW 5; in zone B 1 pressure meter was placed (6). The following sources supply the system:
PW 3 (Gugunighat) supplies zone C, excluded from test.
PW 4 (Bagmamudah) supplies zone A (B), switched on and off.
PW 5 (Zamindarparg) supplies zone A (+B) or fills up OHT, switched on and off.
PW 2 (Zamindarparg) submersible, out of operation.
OHT (Zamindarparg) supplies zone A + B, switched on and off.

The following operation schedule was kept during the test:

Scenario I, up to 11:50: PW 4 and PW 5 supply A+B

Scenario II, 11:50-12:20: OHT supplies A+B

Scenario III, 12:20-12:45: OHT supplies zone A

Scenario IV, 12:45-13:10: PW4, PW5 and OHT supply zone A

Scenario V, 13:10-13:30: PW4, PW5 and OHT supply zone A+B

The following table summarizes the pressures found under the above scenarios.

Scenario	1	2	3	4	PW 4	5	PW 5	6	7
I	2.5	0.5	2.7	3.0	-	3.8	11.0	1.0	0.5
II	4.0	1.0	5.0	-	NA	11.0	NA	1.6	0.8
III	5.5	1.4	5.7	7.3	NA	11.0	24.0	NA	1.0
IV	9.5	2.7	11.7	-	15.5	13.5	21.5	NA	1.35
V	9.2	2.2	9.5	9.0	12.5	14.5	19.5	-	1.2

Pressures are in mwc. NA indicates "not applicable", - indicates "no reading".

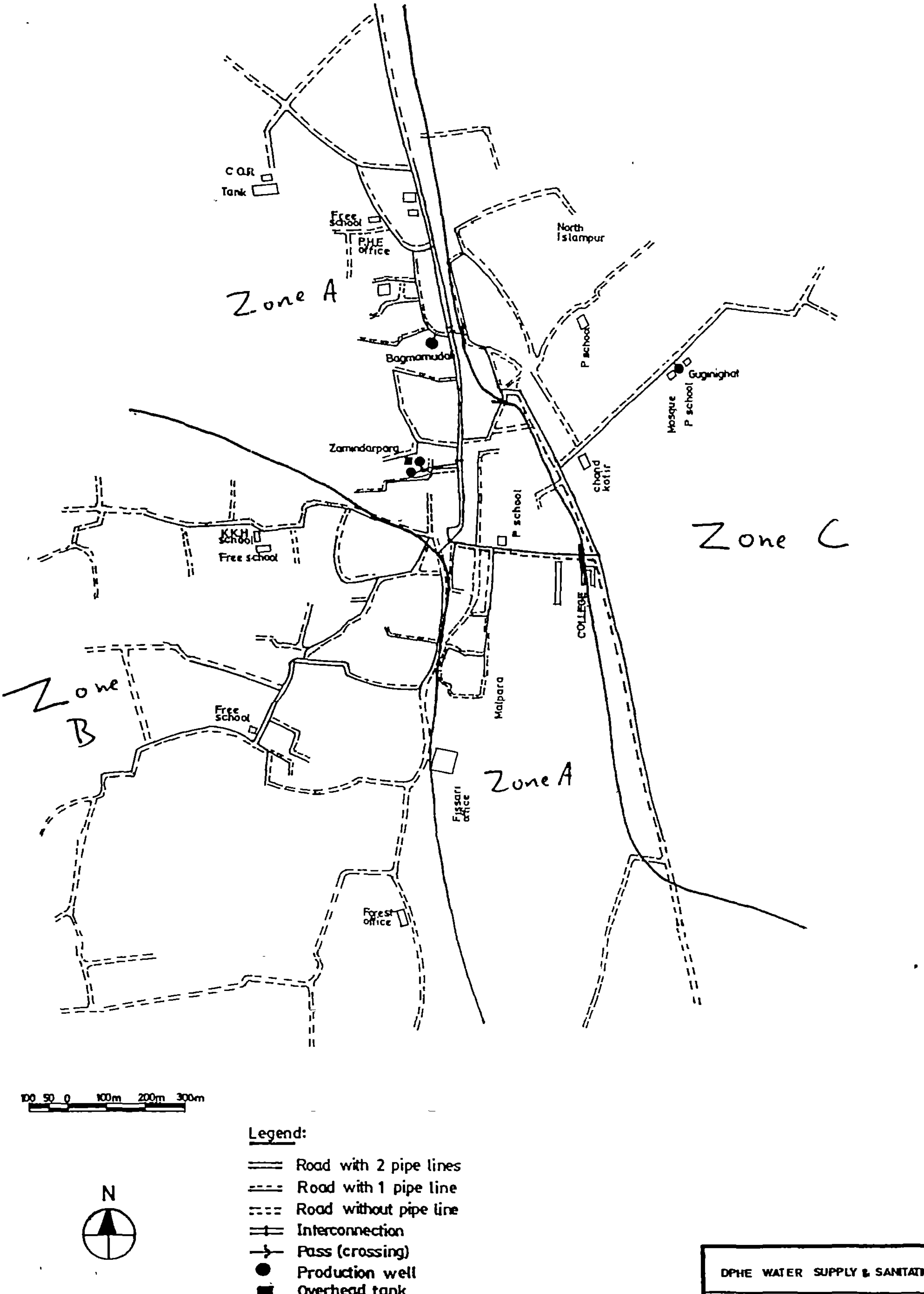
Discussion

Operating the full system with pumps only (I) is inefficient. Low pressures all over, even location 5 next to the water works has only 3.8 m. Operating the full system with OHT only (II) gives better pressures, and when only zone A is supplied (III) pressures improve somewhat further. A significant improvement is noted when zone A (IV), or even the full system (V), is supplied by a combination of pumps and OHT.
The system fringes are represented by location 2, 6 and 7. It must be concluded that pressures in these fringes remain low under all supply scenarios. While these low pressures may indicate specific large leaks around locations 2, 6 and 7, it may also indicate the system is, more generally, overloaded by excessive waste/leakage.

N.B. 1 The high pressure at PW 5 during scenario III is caused by the fact that PW 5 was refilling the OHT at that moment.

2 At location 5 a pressure increase is recorded from scenario IV to V, whereas a decrease might be expected. The demand area around location 5 is small, and a few consumers closing their taps may have caused this increase.

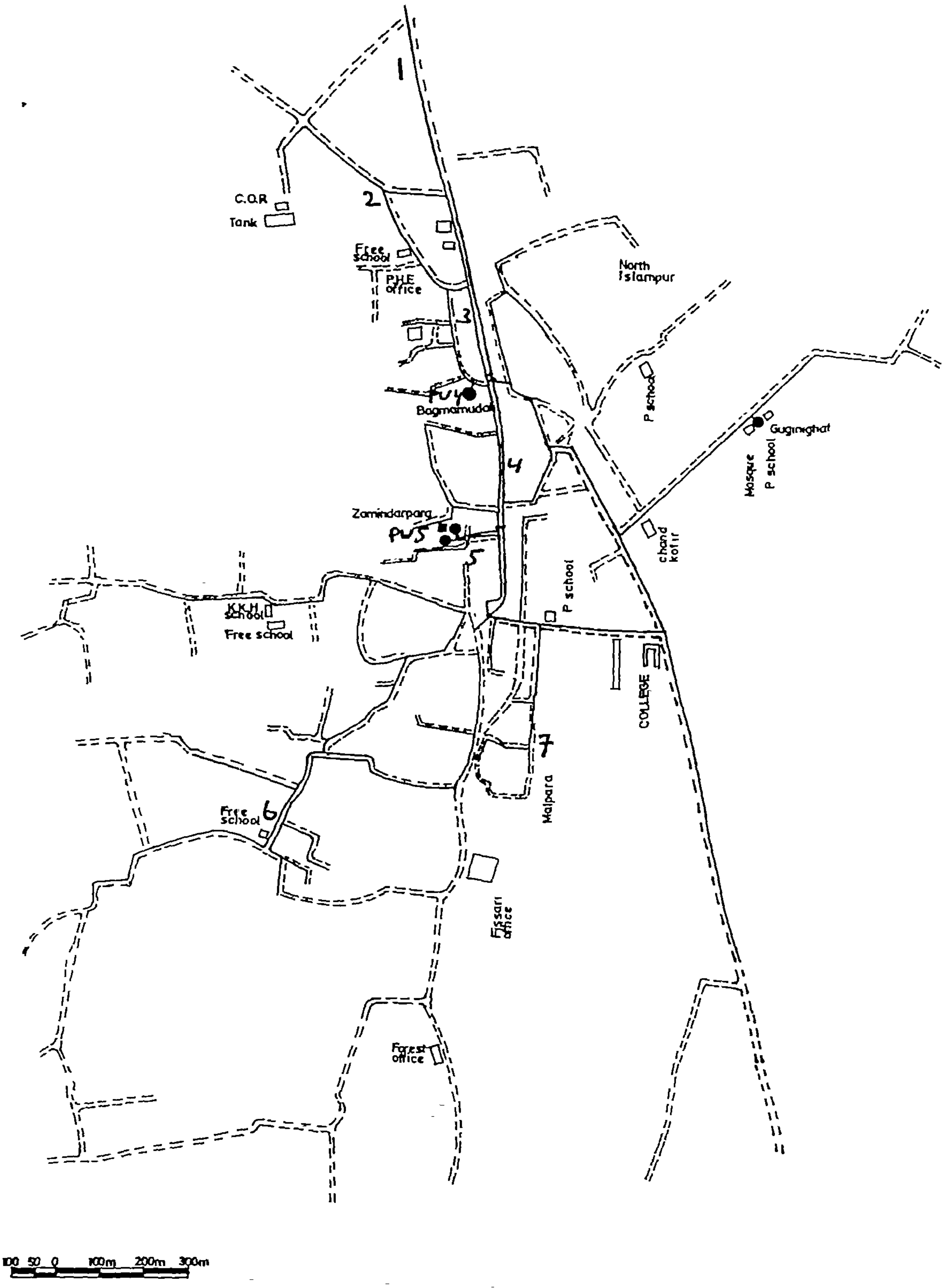
3 For the low pressures in the fringes it is felt that at location 2 the cause may be a major local leak/waste, at location 6 it is more likely to be structural overload of the system, whereas for location 7 it is difficult to assess.



DPHE WATER SUPPLY & SANITATION PROJECT

MUNSHIGANJ

DATE. 15.2.90 DRG.NO. D19/2/90	LAYOUT OF ROADS & PIPE LINES

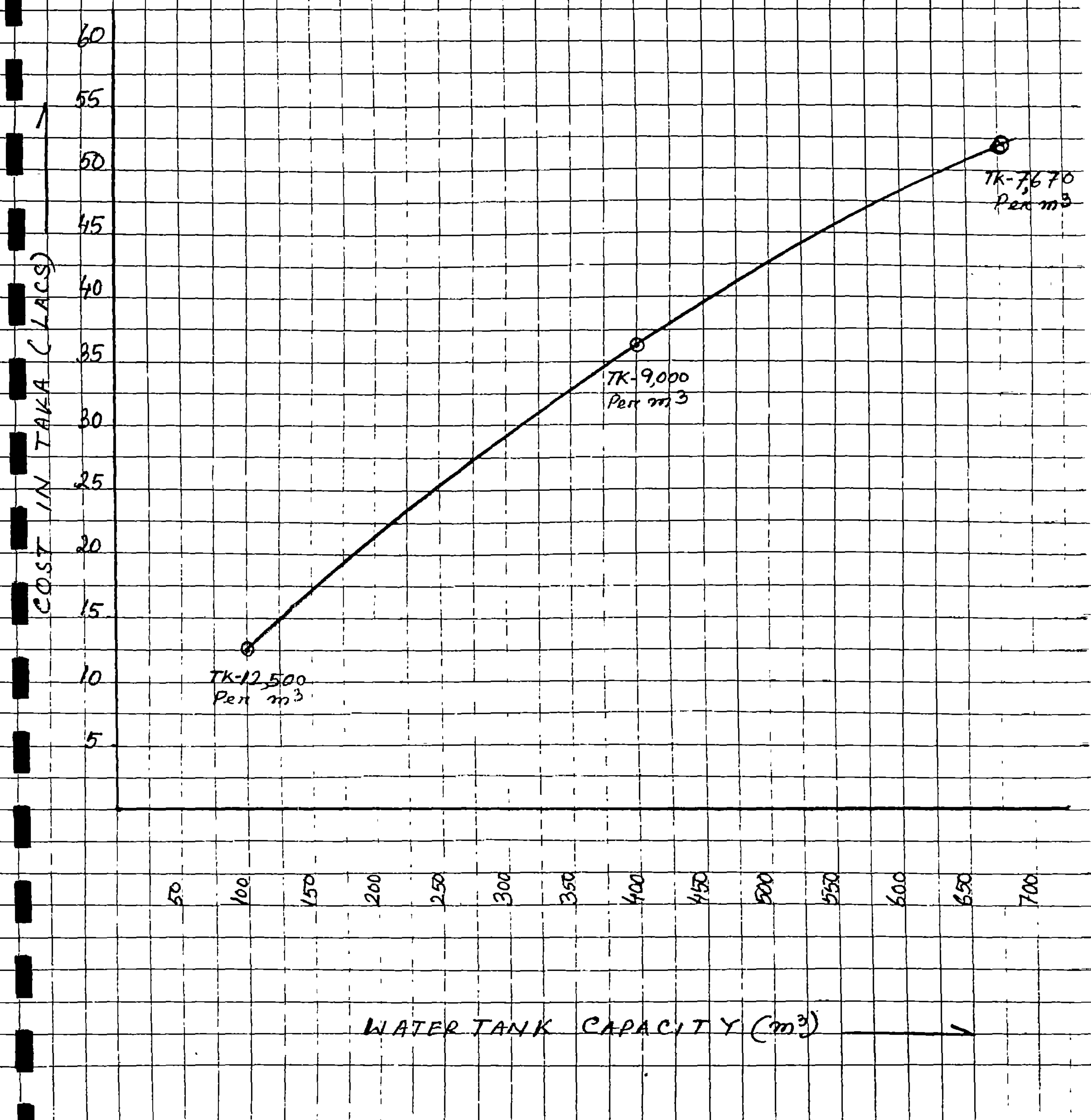


Legend:

- Road with 2 pipe lines
- Road with 1 pipe line
- Road without pipe line
- Interconnection
- Pass (crossing)
- Production well
- Overhead tank

DPHE WATER SUPPLY & SANITATION PROJECT	
MUNSHIGANJ	
DATE. 15.2.90 DRG.NO. DT9/2/90	LAYOUT OF ROADS & PIPE LINES

ANNEX 3 COST OF RESERVOIR RELATED TO VOLUME



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