APPENDIX 2
CPW CASE STUDY PIPED OPTION

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CPW CASE STUDY PIPED OPTION

1.0 Introduction

1.1 Background

A case study on the preliminary design and costing of a piped and open channel distribution system was completed for part of the Central Plains Water (CPW) area. These designs and costing were to provide the basis for establishing a generic method for comparing the pros and cons of large scale open channel and pipe distribution systems, by using the case study investigation to surface the main generic issues.

The CPW case study is also of interest to the Central Plains Water Ltd (CPWL), the entity promoting the CPW scheme, because of the widespread attention being given to the choice of a water distribution option by the CPWL shareholders. CPWL has contributed to the funding of this study.

A piped design option of a sub-area of the CPW scheme proposals was completed on the area of land located between the Rakaia and Selwyn River below the proposed CPW headrace to the Main South Road (SH1).

The detailed description of the design process for the piped option is a blueprint of the process that should be followed in similar investigations. The design process needs to address the following issues at the design criteria stage and then into detailed feasibility design:

- Setting the Design Criteria:
- Area to be served
- System Capacity
- Water Source Issues
- Topographic Issues
- On Farm Delivery Characteristics
- Pressure Control
- Layout Options and basis of optimization
- Turnouts
- Pipe Material
- Role of on-farm pumping
- Estimation of capital and annual costs

2.0 Design Details

URS[1] provided a plan showing the following details of the CPW scheme (refer to Figure 1):

- Location of CPW headrace
- Boundary of the total proposed irrigated area (relevant to this study)
- Property boundaries and property area
- Contour details (10 m contours)
- Proposed open channel layout

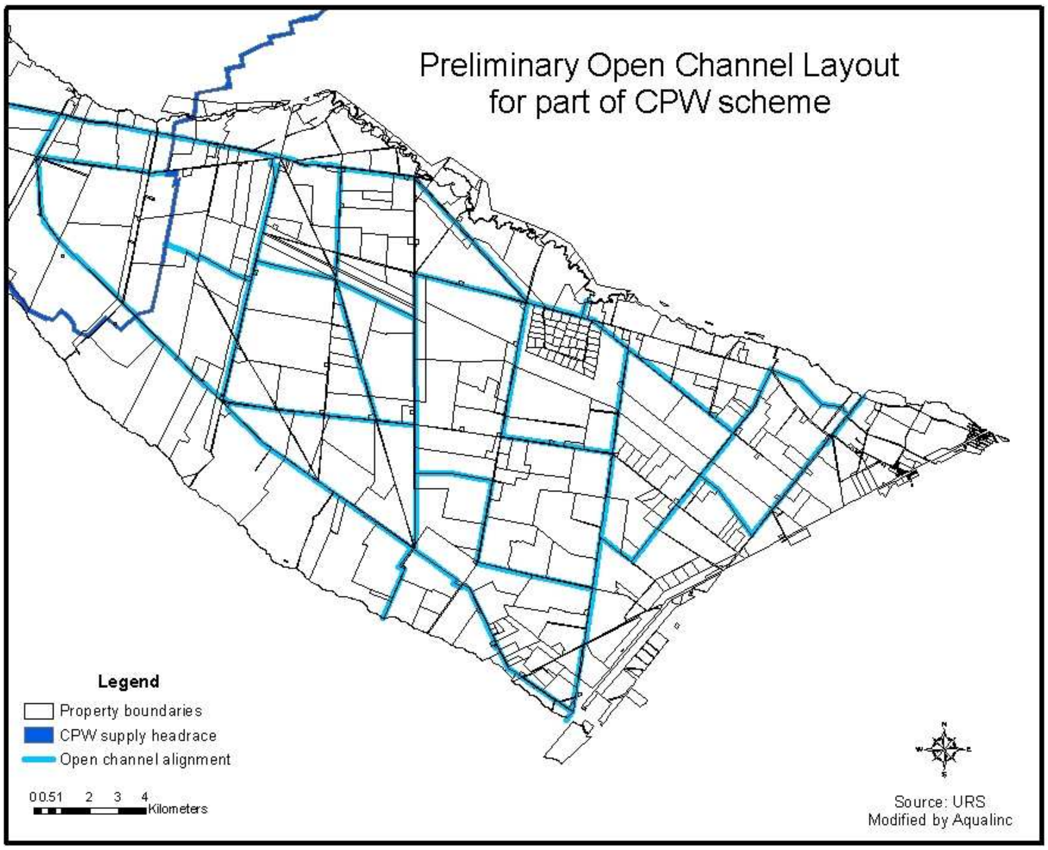

Figure 1: Preliminary open channel layout for part of CPW scheme

Water is to be abstracted from the CPW headrace, and will be delivered to the proposed irrigable area via a pipe network or open channel. The water will be delivered to each property using an off-take point (turnout).

2.1 Irrigated Area

The total area to be irrigated in the case study sub-area is approximately 36,000 ha or some 60% of the total area proposed for the CPW scheme. Within this area, there are 305 turnouts to deliver water to each property. Some turnouts will deliver water to more than one property. There are 133 properties with turnout flow requirements of less than 1 l/s. These

[11] URS is the technical consultant to CPWL.

turnouts account for less than 1% of the total flow and are not included within the irrigated area.

2.2 System Capacity

The system capacity has been based on a delivering a flow of 0.6 l/s/ha[2] to each property. The total flow to supply an area of 36,000 ha is therefore 21.6 m^3/s.

The design is to be capable of supplying water to each property 'on demand' at all times[3].

2.3 Water Source

The water source is from the CPW headrace and thus provides flexibility in abstraction points, including the possibility of multiple off-takes.

2.4 Elevations

The highest elevation at the CPW headrace is at 240 m amsl and the lowest elevation is at the Main South Road at 63 m amsl.

The contour information as supplied by URS has been used. It is considered appropriate to use 10 m contours as interpolation between these contours gives a reasonable estimation of the lie of the land between the contours.

2.5 On Farm Delivery Pressures

The elevation change over the length of the pipe network provides additional pressure within the scheme, which means that properties can be delivered with water under pressure. This additional pressure in the system also enables smaller diameter pipes to be selected, as the elevation gain largely offsets the additional friction losses within the smaller diameter pipes. However, this will increase on farm pumping and a balance between reducing pipe capital costs and on farm pumping costs needs to be reached.

The approach taken was to minimise pipe diameters while maintaining a minimum delivered pressure to the turnout under full demand. In practice, due to the diversity of land use and management practices, it is anticipated that the scheme will only operate under full flow demand for short periods of time. For most of the time, particularly at the shoulders of the season, the flow demand will be less than 100% and at these times pressures delivered to the turnout will be higher, thus reducing pumping requirements. Many of the turnouts may not require pumping at all. The trade-off with this approach is that slightly more on-farm pumping is likely to be required than if the pipe diameters were selected based on a lower velocity. Therefore it is important to consider both capital and operational costs when considering the final costs of the scheme.

2.5.1 Turnout Delivery Pressure

A minimum pressure of 5 m was to be supplied to all turnouts under full flow conditions. This is to minimise issues with pump priming and negative pipeline pressures.

At the top of the scheme it has not been possible to achieve a minimum pressure of 5 m under gravity supply for some of the turnouts.

[2] This supply rate is adequate for irrigated pasture in the study area.
[3] On-demand operation is a basic criterion for both the open channel and piped options.

2.6 Pressure Control

Due to the significant elevation change throughout the network the scheme may be subjected to high static pressures. In the CPW case, static pressure will be higher than dynamic pressure and was the main focus regarding pressure control. Options for managing static and transient pressures include use of pressure control technology; in-pipe power generation to "burn-off" excess pressure; or use of piped material that is capable of withstanding pressure requirements with an adequate factor of safety.

The option selected for this design study was to design the distribution pipelines to withstand static pressures. Pressure control-on farm as part of the turnout was assumed, which enabled lower pressure class pipe to be used on-farm. Typically lower specification pipes and construction occurs on on-farm irrigation systems, therefore it is important to isolate the risk of high pressure from the network.

Transient pressures should be modelled at the pre-feasibility stage of any design, and other pressure control options explored[4].

2.7 Pipe Layout and Sizing

The pipe layout and pipe sizing was based on minimising the capital cost of the distribution pipeline to deliver a minimum of 5 m pressure to the turnouts[5].

It was assumed that there were no pipe layout constraints, that the pipeline was not restricted to roads and property boundaries and that impact of existing services was not an issue.

2.8 Turnouts

Turnouts from the scheme distribution system will require some or all of the following basic components:

- Pressure reducing valve and pressure relief valves to control excess pressures
- Flow control
- Flow meter

Because specific turnout locations have not been specified, they were placed on property boundaries so that lateral pipe lengths could be reduced.

2.9 Pipe Materials

Although any pipe type could be considered, fibre reinforced pipe (FRP) has been used for the design, one of the reasons being it has the ability to withstand high pressures. Also, the risk of the pipe deteriorating with age is low, so that the pipe roughness is unlikely to increase, thus scheme performance should be maintained throughout the pipes life. Nominal diameters have been used within the design.

[4] The review meeting raised the issue that transient pressures may require higher rated pipe. Detailed transient analysis undertaken for a scheme with similar characteristics (Barrhill Chertsey in Mid Canterbury) showed that static cut-off pressures were critical.

[5] A number of combinations of pipe sizes were investigated and this design solution minimized NPV of capital and operating costs. This may be different in other circumstances.

2.10 On Farm Pumping

Water is to be supplied to each turnout under pressure. However, due to friction losses or changes in elevation along the pipe network, a reduced amount of on-farm pumping may be required. To operate the on-farm irrigation system effectively, a minimum pressure of 50 m has been assumed. Where less than 50 m pressure is delivered under gravity, small on farm booster pumps will be required.

To aid in the assessment of on-farm pumping requirements, land use projections and monthly and seasonal irrigation demand estimates were scaled from irrigation demand modelling undertaken in the Ashburton region. This was the basis for the criteria used for determining the change in irrigation demand through the irrigation season and the operational costs for on-farm pumping.

Due the variation in pumping pressure and flow required throughout the season, pumps fitted with variable speed drives have been assumed.

2.10.1 Irrigation Demand

A water demand scenario for the Ashburton region was modelled in the Canterbury Strategic Water Study (2002), to determine average and peak monthly irrigation demand. A daily time series of potential irrigation demand was calculated in the Ashburton region using daily rainfall and climate data from June 1972 to May 2000 based on the land-use assumptions summarised in Table 1. Both the monthly peak flow demand and average monthly flow demand were calculated.

Table 1: Assumed land-use for potentially irrigable land

Region	Dairying	Intensive Livestock and Dairy Support	Arable
Ashburton	52 %	30 %	18 %

To estimate the potential irrigation demand for the Rakaia/Selwyn scheme, the data from the Ashburton region has been scaled, based on the peak flow difference between the Ashburton and CPW, thus enabling the monthly flow demand to be calculated. The average flow demand as a percentage of the peak flow for each month is shown in Figure 2.

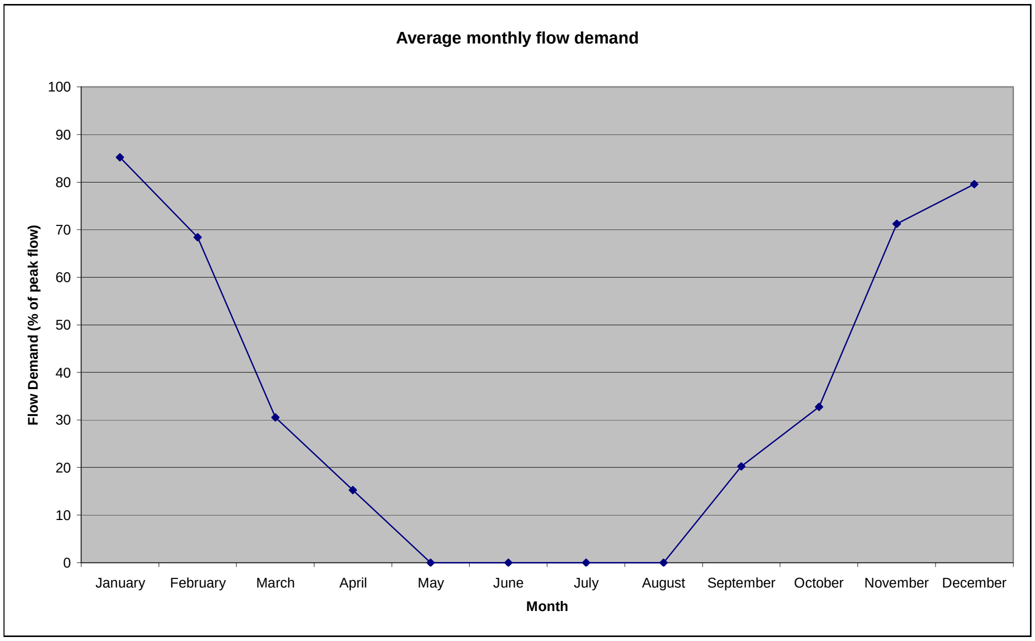

Figure 2: Average monthly flow demand

3.0 Hydraulic Design

The plans showing the property boundaries and scheme layout, supplied by URS, were imported into Irricad™ irrigation design software.

Firstly, the pipe layout was optimised based on reducing pipe capital cost.

Secondly, a detailed hydraulic analysis was completed, to finalise the pipe diameters of the network to ensure all design requirements and appropriate design limits were met.

Thirdly, based on the finalised pipe layout and pipe diameters, on-farm pumping costs were estimated.

Finally, an assessment on the trade-off between pipe capital cost and on-farm pumping was completed based on considering the NPV for the network.

3.1 Pipe Layout

3.1.1 Design Options

During the pipe layout optimisation process, the pipe capital cost for one intake point from the race compared to multiple intake points was compared. Three main options were considered regarding the pipe layout, as follows:

- Option 1 – one intake from the CPW headrace with one main distribution pipeline taking the most direct route with lateral branches to supply the turnouts
- Option 2 – three intakes from the CPW headrace with three main pipelines taking the most direct route with lateral branches to supply the turnouts.
- Option 3 - three intakes from the CPW headrace with one main pipeline taking the most direct route with lateral branches to supply the turnouts. Small pipelines will deliver water to the turnouts at top of scheme.

For all pipe layout options the following method was followed.

3.1.2 Method

Entering data into Irricad
Based on the plans supplied by URS the following information was entered into Irricad™ irrigation design software:

- Scheme boundary
- CPW head race
- Property boundaries
- Contour information

All turnouts were entered into the modelling software based on supplying each property at the required flow rate determined from scheme system capacity (0.6 l/s/ha) multiplied by area of the property. Then the pipeline for Options 1, 2 and 3 were entered in, taking the most direct route as possible to minimise the length of larger diameter pipe. Lateral pipelines branching off from the main distribution pipe were used to supply the turnouts.

Pipe layout optimisation
To optimise the pipe layout, changes were made to the layout while comparing pipe capital costs to assess whether the revised layout was more cost effective.

To effectively compare capital costs between each scenario, a quick assessment of the pipe diameters required throughout the network for different layouts is required. The method needs to be repeatable and provide for a consistent and comparative approach for assessing the different layouts.

To quickly assess the pipe sizes for each pipe layout iteration, the pipe diameters throughout the entire network were sized based on a maximum velocity. The maximum velocity was selected so that a positive (essentially greater than 1 m) pressure was delivered to the majority of turnouts and to ensure that the pressure within the main distribution pipe was gaining down the network. This approach meant that typically only pipe diameters on the laterals needed to be adjusted to ensure all turnouts received positive pressure when finalising pipe diameters (see below). The maximum velocity was set to 3 m/s.

Cost savings were made by directing the flow from the main pipeline into smaller branch mains as high as possible in the system, thus allowing a smaller diameter main pipe to be selected. Generally, the cost saving gained by reducing the larger diameter pipe was more than offset by the cost in the increased length of smaller pipe.

Also, the lengths of laterals were reduced by relocating the turnouts. Turnouts were positioned as close as possible to the main delivery pipe to reduce the incidence of two pipes bordering one property. In some cases, this resulted in some turnouts being positioned near the bottom, rather than the top of the property.

3.2 Pipe Diameter

Once the pipe layout was optimised, the pipe diameters were finalised.

Firstly, the turnouts were identified where the delivered pressure was less than the minimum pressure of 5 m. Then pressure loss was checked along the lateral pipes. Where small diameter pipes had high friction losses over a short distance (particularly at the ends of the lateral), these pipes were upsized. Following that, pipes along the lateral which had the highest velocity were upsized until the minimum of 5 m pressure was delivered to all turnouts on that lateral.

The velocity in all pipes was checked to ensure that they were within acceptable velocity limits to reduce the risk of water hammer. Also, static and dynamic pressures were assessed throughout the scheme selected pipe classes to ensure that the pipe pressure limits were not exceeded.

3.3 On Farm Pumping

3.3.1 Pump Size

Using the final pipe layout and pipe diameter, the pressure delivered to each turnout at 100% flow demand, i.e. when all turnouts were operating, was determined. Based on a minimum pressure of 50 m to operate the on farm irrigation system, the turnouts that required on-farm pumping and the pump head required was identified.

Assuming a pump efficiency of 75% and a motor efficiency of 90%, the pump size required at each turnout was calculated.

Using pump capital costs (supplied by Flowserve) and electrics cost data (supplied by Nairn Electrical) a relationship between capital cost and pump size was derived for a variable speed drive pump, as follows.

Pump capital cost ($) = 571.5 x Pump size (kW) + 15,196

Based on this data, total pump costs were calculated.

3.3.2 Pump Energy Cost

To enable calculation of the seasonal pump energy cost, the pressure delivered to each turnout for the average monthly flow demand was modelled (described above). This allowed average monthly pumping requirements to be calculated.

The number of hours that the turnout would have been operating at maximum flow within that month has been calculated based on the flow demand. For each month within the irrigation season, the on-farm pumping requirement has been calculated and then combined to give total season pumping requirements.

Based on the following energy charges within the region (supplied by Meridian), the annual energy costs were calculated:

- Daily charge $2.82/day = $1029/yr
- Energy charge 0.13c/kWh
- Capacity charge 0.32c/kVA/day = $123/kW/year (assuming a power factor correction of 0.95)

4.0 Results

4.1 Pipe Layout

During the pipe optimisation process, Option 2 was selected as the preferred option to be investigated further, because it was the lowest capital cost. The final pipe layout was a variant of Option 2 and 3 with three intakes from the CPW headrace. Two main pipelines with lateral branches supplied the majority of the irrigated area with small diameter pipes delivering water from the other intake to turnouts near the top/middle of the scheme. The final pipeline layout is shown Figure 3.

The greatest cost savings could be made when the route was not constrained to property boundaries and road corridors, which allowed the most direct pipeline route to be chosen. This reduced the length of larger diameter pipe, which is where the majority of the cost savings could be made. The flexibility in locating a piped water supply distribution system and the option of multiple intakes, also contributed to significant savings.

Once a main layout had been chosen, it was found that minor changes in the layout actually resulted in only small percentage changes the overall pipe capital cost. It was not considered necessary to perform numerous iterations for the purpose of the study.

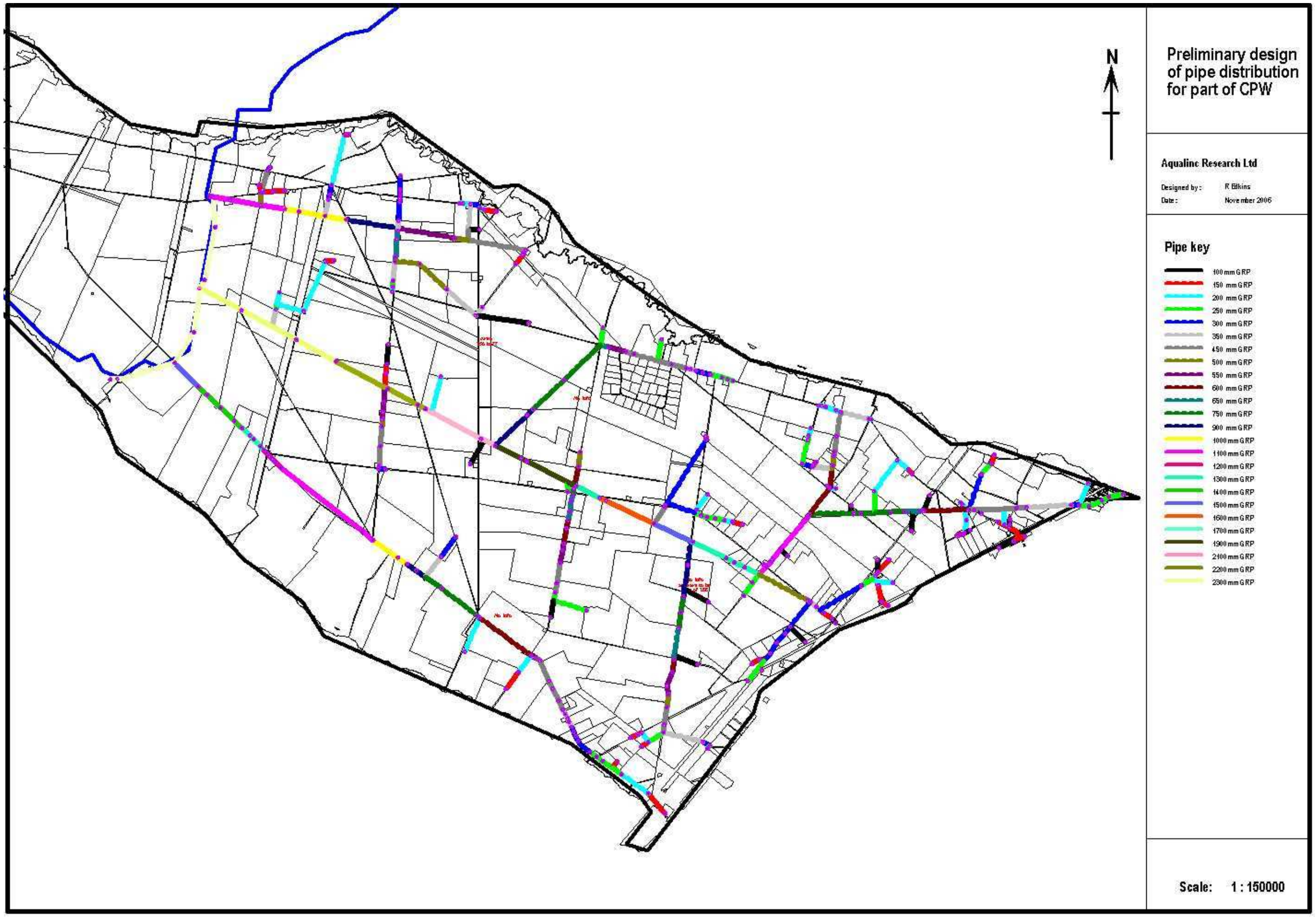

Figure 3: CPW - proposed pipe layout

4.2 Pipe Diameter

The pipe diameter and pipe class was selected to meet velocity and pressure requirements.

The bill of materials for the preliminary pipe distribution network is summarised in Table 2.

Table 2: Bill of materials – pipe lengths (m) for each class and diameter

	Pipe Class					Total pipe length (m)
FRP	**PN6**	**PN9**	**PN12**	**PN15**	**PN18**	
100mm	660	3,010	590	3,160	2,610	10,030
150mm	2,110	860	800	3,810	3,620	11,200
200mm	6,190	1,710	1,410	4,730	3,250	17,290
250mm	400	-	4,390	5,580	2,410	12,780
300mm	2,280	1,190	3,870	5,690	1,510	14,540
350mm	2,070	3,360	950	3,300	1,460	11,140
450mm	2,050	2,240	5,590	2,250	1,900	14,030
500mm	1,450	1,640	660	2,750	-	6,500
550mm	1,040	1,880	1,350	770	-	5,040
600mm	-	-	3,470	2,130	1,450	7,050
650mm	1,090	130	1,090	1,030	610	3,950
750mm	-	3,470	1,980	3,660	470	9,580
900mm	1,700	2,440	1,590	250	-	5,980
1,000mm	2,020	1,360	-	-	-	3,380
1,100mm	6,320	-	-	2,560	-	8,880
1,200mm	800	-	-	-	-	800
1,300mm	990	-	-	2,460	-	3,450
1,400mm	1,970	-	-	-	-	1,970
1,500mm	1,090	-	1,330	-	-	2,420
1,600mm	-	-	1,960	-	-	1,960
1,700mm	-	-	930	-	-	930
1,900mm	-	1,160	1,720	-	-	2,880
2,100mm	240	2,320	-	-	-	2,560
2,200mm	3,290	-	-	-	-	3,290
2,300mm	5,030	-	-	-	-	5,030
					Total pipe length (m)	**166,660**

4.3 On Farm Pumping

4.3.1 Pump Capital Cost

The preliminary on-farm pump size and pump capital costs for the piped distribution system and the open channel system are summarised in Table 3.

Table 3: Preliminary on-farm pump size and pump capital cost

Option	Total pump kW	Pump capital Costs
Pipe	6,746	$ 7,623,755
Open race	14,421	$ 10,583,810

4.3.2 Annual Energy Cost

Table 4: Preliminary on-farm annual operational costs

Option	Annual on-farm pumping cost
Pipe	$ 2,556,250

4.3.3 Trade-off Between on Farm Pumping and Pipe Capital Costs

It was found that when sizing the pipe diameters for a lower velocity, pipe capital costs increased due to larger diameters being used. However, the reduction in pump capital cost and annual pumping did not offset the increase in pipe capital. The assumption of supplying minimal pressure to the turnouts under full load is justified.

4.3.4 Pressure Delivered Under Different Flow Demands

To demonstrate the pressure variation delivered to the turnouts at different flow demands, eleven representative turnouts were selected located near the top, middle and bottom of the scheme. The pressure delivered to these turnouts (location shown in Figure 4) has been assessed for different flow demand scenarios, ranging from 0 to 100% demand.

Figure 5 shows the pressure delivered to Turnout 387 (located near the top of the scheme), Turnout 602 (located near the middle of the scheme) and Turnout 296 (located near the bottom of the scheme). This shows that for the turnout located near the top of the scheme that under different flow demands the pressure delivered to the turnout varies little. However, for the turnouts located near the middle and bottom of the scheme, some pumping may be required at 100% flow demand (assuming 50 m head is required), but when the flow demand reduces to around 80%, pumping requirements for these turnouts would be minimal.

Figure 6 demonstrates the number of turnouts that would require pumping throughout the season.

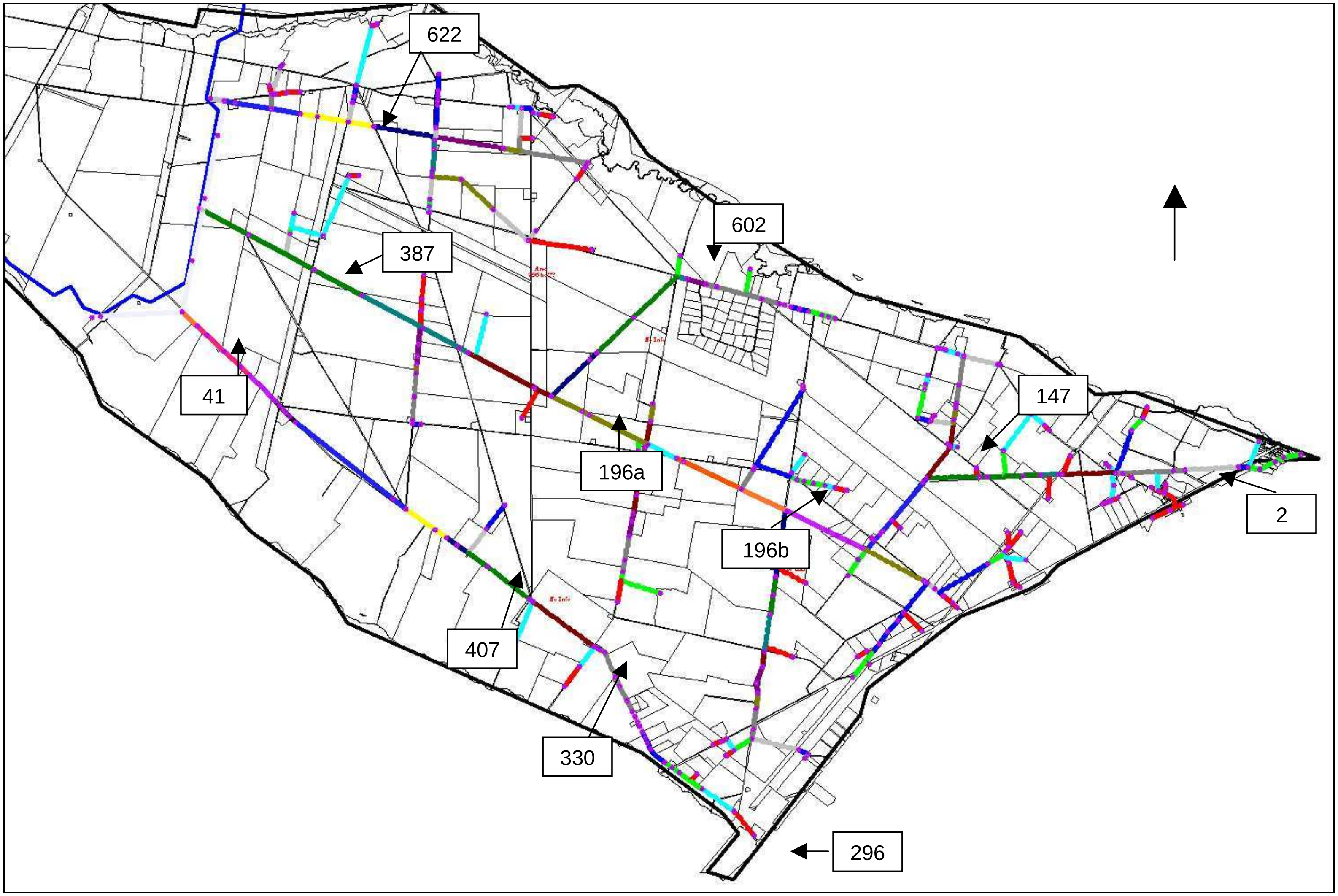

Figure 4: Option 2 - Pipe Layout and turnout location

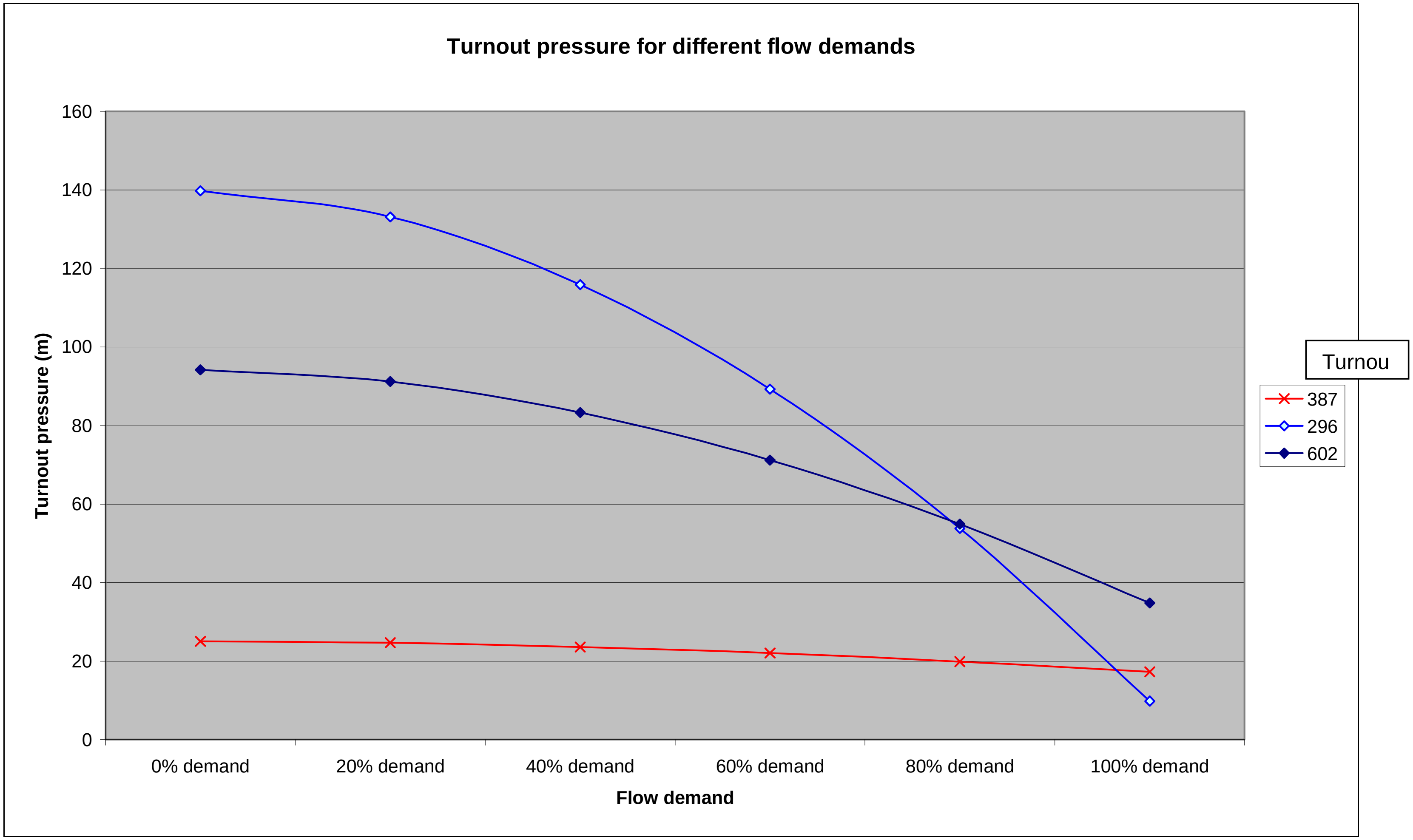

Figure 5: Turnout pressure for different flow demands, for turnouts located lower within the scheme

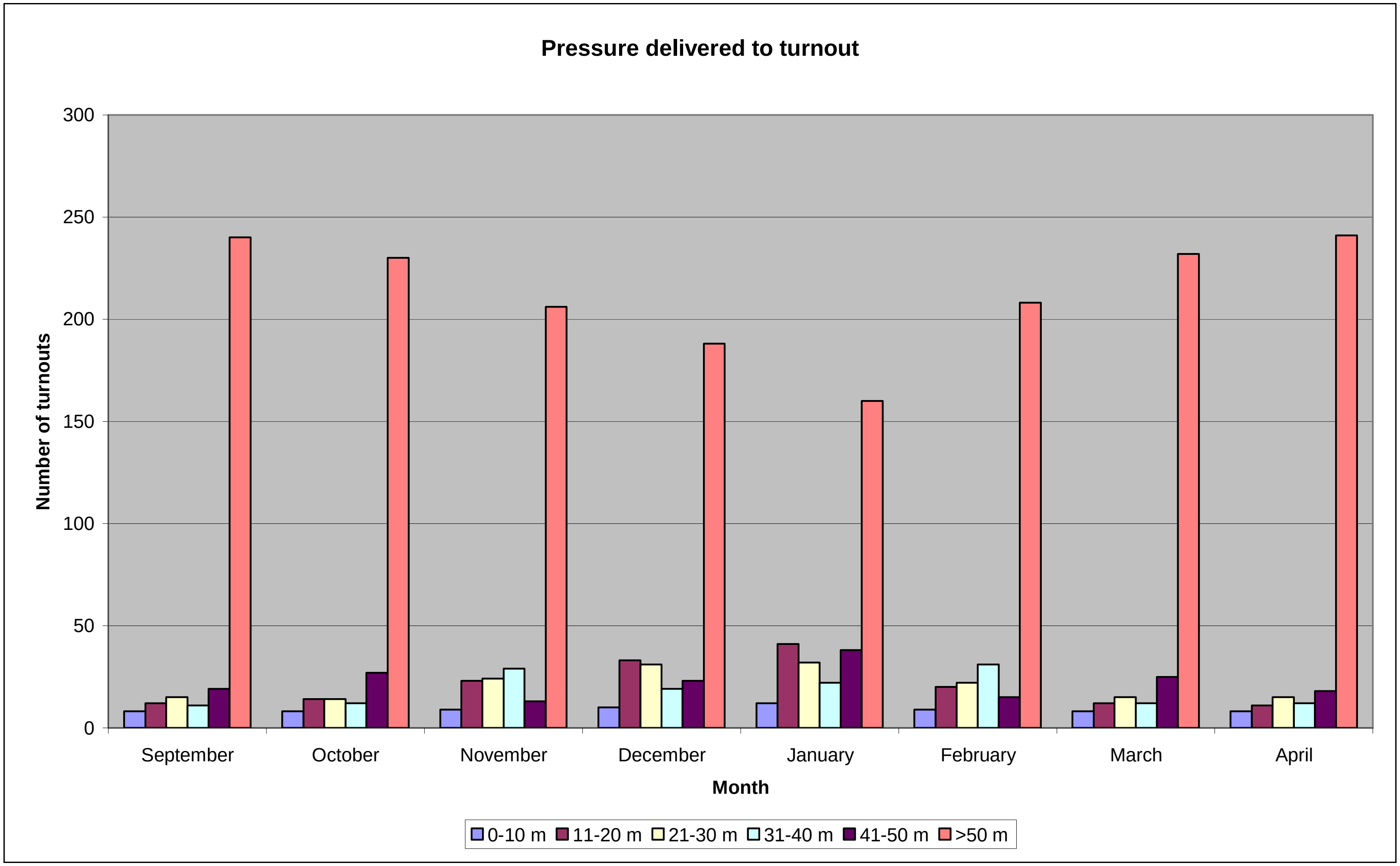

Figure 6: Turnout pressure for different flow demands, for turnouts located lower within the scheme