INCREASING THE CAPACITY OF EXISTING PIPED AND OPEN CHANNEL ASSETS
Development of the Jet Boost Pump Concept

Matthew Sheppard and Ben Pritchard – Jacobs New Zealand Limited

ABSTRACT

The **jet boost pump** concept was developed as a practical method of boost pumping piped and open channel assets to increase flow capacity, to eliminate or offset the need for new infrastructure and enable deferment or reduction in capital expense.

The jet boost pump concept is a modification of the conventional jet pump and works by diverting a portion of the flow, pressurising it and then returning it as a high energy jet. The jet energy is transferred to the flow via turbulent mixing and entrainment. Energy transfer efficiency in the order of 10% to 25% and the addition of 0.5m to 2.0m energy head is achievable in a single pumping application.

Research undertaken with the University of Canterbury tested and validated the jet boost pump concept and established preliminary design methods using experimental data and non-dimensional analysis.

Jet boost pumps have potential use particularly where hydraulic grade lines are 'flat', velocities are slow and the cost of conventional engineering solutions is high. Potential applications include storm water and sewer trunk mains, open channel drains and ocean outfalls.

This presentation will outline the concept, establish hydraulic principles, outline the development and testing undertaken to date and present worked examples of its potential application.

KEYWORDS

Jet Pump, Boost Pump, Pumping Station, Capacity Increase

1 INTRODUCTION

Many towns and cities around the world have piped and open channel assets that are in good condition but are under capacity and require major capital expense to upgrade or replace.

The authors sought to identify a practical method of boost pumping piped and open channel assets to increase flow capacity, to eliminate or offset the need for new infrastructure and enable deferment or reduction in capital expense. A combination of previous experience with gold dredging, conceptual hydraulic analysis and applied research has led to the development of the **jet boost pump** concept.

Jet pumps are commonly used in the oil and gas industry as well pumps and in rural fire fighting to pump water from low lying and inaccessible water reservoirs and the hydraulic theory is well established.

In a conventional jet pump, a high velocity turbulent jet is introduced at the 'suction chamber'. The high velocity jet flow entrains the suction liquid with complete mixing of the pumped and suction fluid occurring in the mixing chamber and diffuser section. The kinetic energy (velocity head) of the jet is converted to potential energy (pressure head) with energy losses due to friction and turbulence. Resulting energy transfer efficiencies are in the range of 25% up to 40% (I. Reddy and Kar, 1968 and II. Shizimu et al, 1987).

Schematics of conventional central and annular jet pump configurations are shown in Figure 1 and Figure 2.

Figure 1: Central Jet Configuration

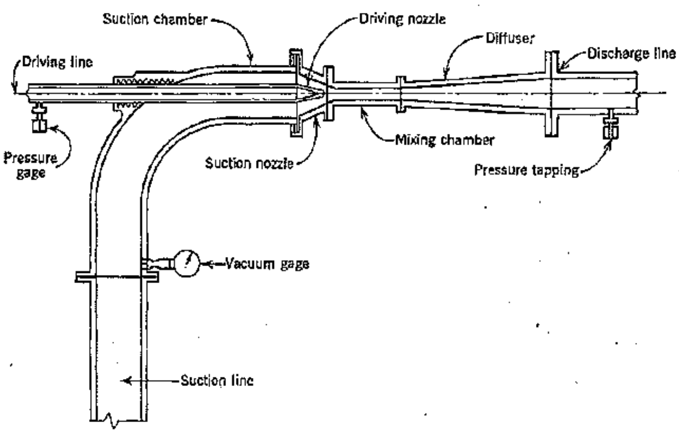
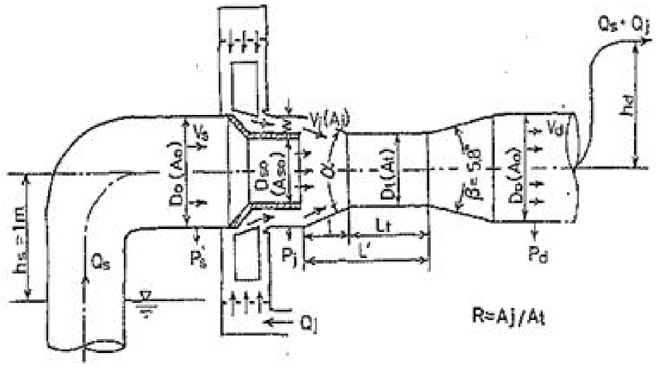


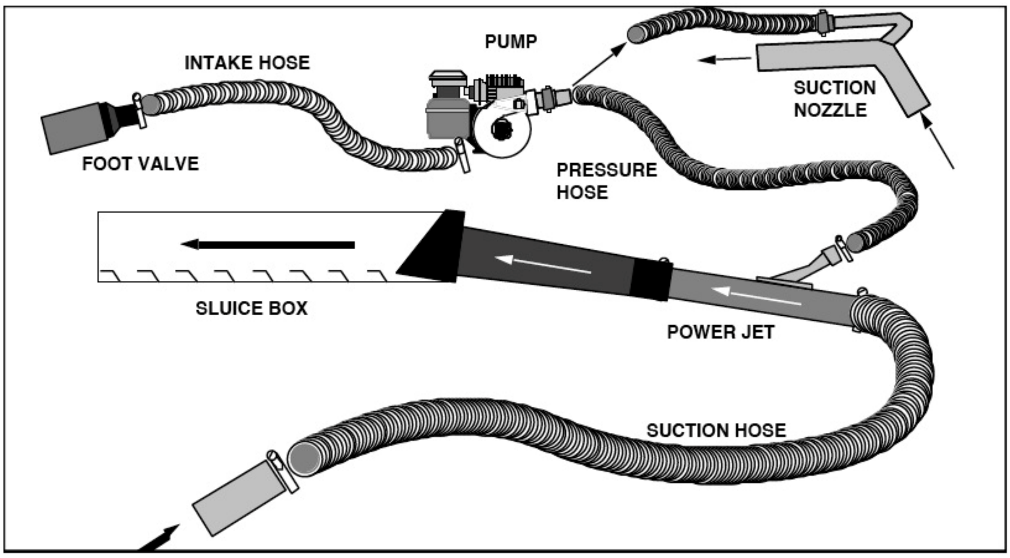
Figure 2: Annular Jet Configuration



The conventional jet pumps shown in Figure 1 and Figure 2 are not suitable for local authority application as there are flow constrictions and rag collection points which would lead to blockages and high maintenance. Accordingly there is little use of jet pumps in this sector. A simplified jet pump configuration with clear passage and large flow rates is used in suction dredges and in theme park 'lazy' rivers, which are more similar to applications in local authority infrastructure.

Figure 3 shows a typical gold dredge configuration where the jet pump has been simplified by introducing the jet discharge through a straight segment of pipe wall ("power jet") without protrusions or complicated arrangements. While slightly less hydraulically efficient than a conventional jet pump, the clear passage and ability to pass large solids makes this arrangement more suitable to Local Authority applications.

Figure 3: Typical Gold Dredge Jet Pump Configuration (source - www.rosewindminingsupply.com)



The jet boost pump concept has similar hydraulic principles to the conventional jet pump but adopts the simplified jet arrangement of the suction dredge and lazy river applications so that it is applicable at the scale associated with Local Authority piped infrastructure and open channels.

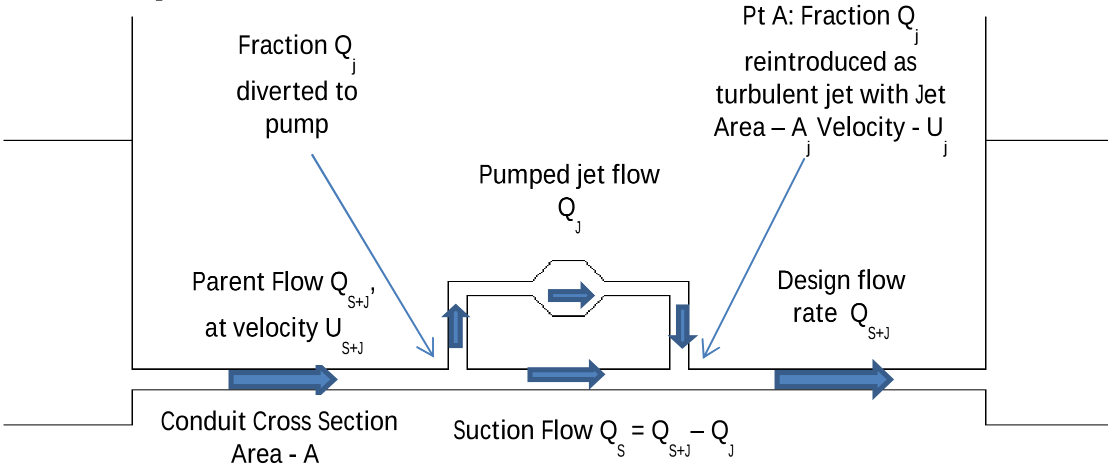
2 HYDRAULIC PRINCIPLES

The jet boost pump concept is a low-head pump that is applicable as an alternate to a conventional pump station, or more strategically as a means to apply small additions of energy to a system at one or more locations.

The jet boost pump concept works by diverting a fraction of the flow, pressurising it with a conventional pump and then reintroducing it to the system as a high velocity turbulent jet. The kinetic energy of the jet is transferred to the system via entrainment and turbulent mixing. The efficiencies of between 10% and 25% achievable are less than a conventional jet pump due to the simplifications made.

Figure 4 shows a schematic layout and the key parameters of a jet pump station arrangement. A fraction of the flow (Qj) is diverted to a pumping unit and reintroduced at high velocity (Uj) as a turbulent jet.

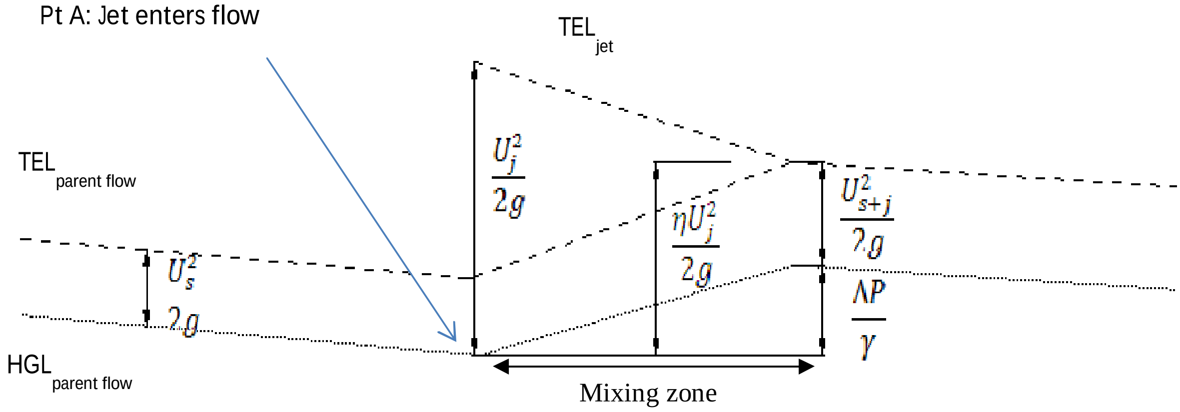
Figure 4: Jet Pump Schematic



The amount of energy transferred to the system is a function of energy input, the portion of flow to which it is applied and the relationship of jet area and flow area. In principle, more energy applied and/or pumping a greater portion of flow will result in greater overall energy head transfer or work.

The pump head (ΔP/γ = pump head in metres) generated downstream of 'point A' is achieved by the conversion of the kinetic energy of the jet into pressure energy through entrainment and turbulent mixing. A total energy line and hydraulic grade line schematic is shown in Figure 5.

Figure 5: Total Energy Line (TEL) and Hydraulic Grade Line (HGL) Across the Jet Boost Pump



The result of the additional energy gained is the same as if the system had a steeper grade or increase in pump pressure of a comparable energy head, being an increase in flow rate in a system with available inflow, or an increase in velocity and reduced depth in a system that is inflow constrained. As a system reaches capacity and becomes less inflow constrained, the response moves more to an increase in flow rate.

The energy input of multiple jet boost pumps across a system is cumulative but remains subject to conventional system hydraulic losses such as friction and turbulence. In this manner the total energy required across a system to achieve the increase in capacity desired can be applied at constraints or where physically feasible. Capacity upgrading using multiple jet boost pumps also enables staging. For example, this would be beneficial in a gravity pipe where 0.5m energy head can be applied before surcharging and associated backwater effects impact the drainage network. If 1.5m energy head is required this can be applied at three locations in the system.

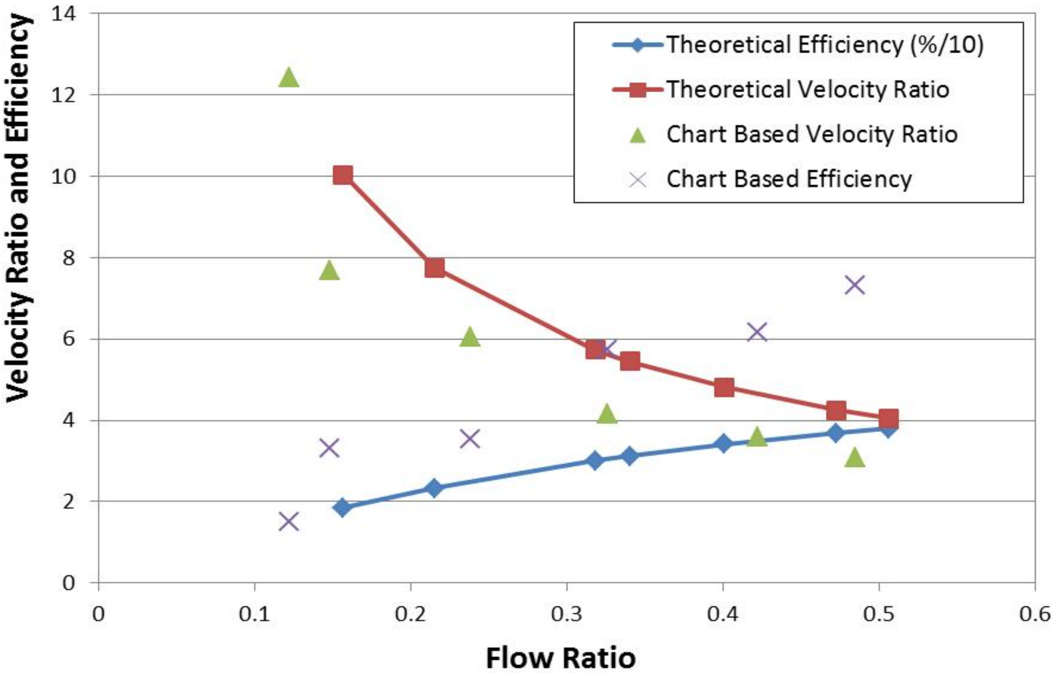
3 DEVELOPMENT AND DESIGN

A research programme was undertaken in conjunction with the University of Canterbury to test and validate the concept and to develop design methods, using experimental data and a non-dimensional analysis.

The first stage of research designed the experimental apparatus and proved the concept using a central jet (III. Davidson. 2010). The second project stage trialled jets introduced at the pipe boundary using various physical arrangements, characterised the jet pump behaviour using a non-dimensional analysis and established and verified design methods.

A first principles solution can be used to physically design a jet pump station. Figure 5 (IV. Pritchard 2010) compares the theoretically estimated and experimentally measured jet velocity and jet flow rate for a particular system. This demonstrates a good 'fit' and that the application of the theoretical solution is conservative.

Figure 6: Comparison of Theoretical and Experimental Values (II. Pritchard, 2010)



Note that "Chart Based" values referenced in the figure above are the experimental values.

Each pipe network or open channel system has its particular arrangement, grades, friction factors and constraints that combine to determine the hydraulic system curve. To achieve an increase in flow, sufficient additional head is required to overcome system losses and analysis of the additional head required utilises conventional hydraulic analysis and network modelling.

Inputs for design of the jet boost pump and design outputs are summarised in Table 1.

Table 1: Design Parameters

Design Inputs	Required system energy (m head)	Design Flow rate	Conduit Cross-Section Area
Design Outputs	Jet Velocity	Jet Area	Jet configuration

Design optimisation of the jet boost pump balances application of less energy to a larger portion of flow against more energy to a smaller portion of flow. The former results in greater physical size and cost and the latter results in smaller size and cost, albeit requiring greater electrical input to achieve comparable performance.

4 APPLICATION OF THE JET BOOST PUMP

The jet boost pump has potential use where-ever additional head or capacity is required in existing infrastructure assets, particularly those that have hydraulic grade lines are ‘flat’, velocities less than 2m/s, land availability is constrained and the cost of pipe replacement or conventional pump station construction is large.

Potential applications include gravity pipes or open channels where increased capacity is required to reduce environmental overflows, enable catchment enlargement or to reduce the likelihood and scale of flooding.

Examples include stormwater and sewer trunk mains, irrigation canals, open channel stormwater drains and streams (particularly where grade has been lost) and ocean outfalls of stormwater systems to counter the adverse hydraulic impacts of sea level rise.

The hypothetical application of the jet pump is presented for several real scenarios below.

4.1 NORTHERN RELIEF TRUNK SEWER - CHRISTCHURCH

The Northern Relief trunk sewer is approximately 14km long and conveys peak wet weather flows in the order of 1.5m^3/s. The network is constructed a very flat gradients, typically in the order of 1:1000, resulting in large diameter reticulation with relatively low flow velocities.

Damage to the sewer network during the Christchurch earthquakes has resulted in greater inflow and infiltration and has increased the frequency of surcharging and environmental overflows during wet weather. This situation is presently being accepted by the regulatory authorities due to the significant challenges faced by Council following the earthquakes, however over time, pressure will mount to reduce overflows.

Current options available to reduce overflows are costly due to the scale of the network and include:

- Continued rehabilitation and replacement of sewer
- New diversions to other wastewater catchments
- Detention tanks
- Replacement trunk sewers
- Pump stations and pressure mains to convey some of the flows

The jet boost pump could be used to provide additional energy at multiple locations in the network to increase wet weather flow rates. A detailed review of the HGL along the trunk sewer has not been undertaken, however some of the locations where the jet pump may be beneficial include:

- Sections of the network with disproportionate hydraulic losses, possibly resulting from localised increases in flows or constraints, where application of additional energy via a jet pump (0.5m head for example) would achieve the same result as replacement with larger pipes
- Sections of the network that are deep and where surcharging could be accepted, where application of additional energy via a jet pump (1.0m head for example) could turn that portion of the network into a "pump", having the effect of steepening the HGL upstream and downstream
- Downstream of environmental overflow locations, where application of a jet boost pump would draw down the HGL upstream of the pump and reduce the frequency of overflows

Application of multiple jet pumps across the trunk sewer in this situation would be significantly easier and cheaper than replacement infrastructure and can be implemented incrementally over time to smooth expenditure.

4.2 DUDLEY DIVERSION STORMWATER RELIEF MAIN – CHRISTCHURCH

The Dudley Diversion is an existing piped gravity main that beheads the upper Dudley Creek catchment and conveys it via gravity directly to the Avon River. It comprises approximately 2840m of 2.1m diameter pipe and 285m of 1.8m diameter pipe and conveys a nominal maximum flow of 6m3/s. Flows in excess of this cause surface flooding at the entry points to the piped system. The asset has more than 50-years asset life remaining and an approximate replacement value of $20M.

The recent earthquakes have resulted in land settlement in the Dudley Creek catchment, reducing the available hydraulic grade causing increased flooding and requiring significant capacity upgrading. One component of the upgrading is to behead more of the catchment, intercepting and pumping approximately 1.5m3/s north to the Dudley Diversion. In this example, increasing the flow capacity of the Dudley Diversion to accommodate the additional 1.5m3/s flow requires approximately 2.2m additional energy head applied across the Dudley Diversion gravity main.

Upgrading the capacity cannot be achieved by pressurizing the gravity main using conventional pumping as this will result in surcharging and overflow. Construction of a pump station and pressure main is feasible and would cost in the order of $10M to $15m, with significant uncertainty and risk due to difficulties in achieving a constructible pipeline corridor and the need for a considerable length of deep construction work.

An approach using jet pumps to boost the capacity of the gravity line could be achieved by implementation of 3 boost stations, each applying approximately 0.7m head to the piped system, placed at strategic locations where construction is feasible and that avoid system surcharging or overflow.

Preliminary design identifies the need for a jet of 1.4m3/s discharging via a 0.3m diameter jet at a velocity of 20m/s to achieve the energy transfer of 0.7m head at each jet boost pump location.

The physical arrangement of the jet pump would likely use axial mixed-flow propeller pumps housed in a precast wet-well with a screened intake off the pipe wall and jet discharge into the pipe. The footprint for each pump station would be in the order of 3m x 6m, which could be located in the roadside berm. Indicative capital costs per pump station would be in the order of $1.5M each or $5M to achieve the overall capacity increase.

The jet boost pump in this situation provides a significantly cheaper means to increase capacity and one that reduces construction programme and risk and allows incremental capacity increase. It also broadens the strategic opportunities available to Council by knowing that additional capacity is available in an existing asset that was not achievable using conventional pumping theory.

4.3 DUDLEY CREEK – CHRISTCHURCH

Dudley Creek is the principle watercourse draining the Shirley, Mairehau, St Albans, Edgeware and Papanui areas and following the earthquakes, land settlement, lateral spread and stream sedimentation have resulted in a significant decrease in the capacity of Dudley Creek. As discussed in the example above, significant capacity increase is required to return the flood risk to pre-earthquake levels.

While Council considers long term remedial options, anticipated to be in the order of $50M capital cost, it has implemented a range of short term solutions aimed at reducing the risk of flood during more frequent storm events. Key flow constraints have been removed and Dudley Creek has been widened and deepened in key areas. Council has also put in place emergency pumping arrangements to protect the low lying Flockton area and has implemented jet boost pumping to increase flow capacity in Dudley Creek.

During recent rainfall event in June 2014, a basic jet pump configuration was trialled, utilising four rental skid-mounted 6” drainage pumps with direct discharge into the barrel of the culvert. A 35% flow capacity increased was demonstrated, from approximately 700 L/s to 950 L/s.

While this increase in flow rate offers only a marginal reduction in flood risk, it is achieved in a very low-cost manner and can be optimised and effort increased if greater capacity is required. Council has now included the jet boost pump in three road culverts as part of its emergency pumping operations. Five discharge jet nozzles have been permanently mounted in these culverts to enable rapid deployment of emergency pumps. It is anticipated these will provide a flow increase in the order of 350L/s to 500L/s.

Application of the jet boost pump in this situation does not resolve flooding, however it contributes meaningfully and in a manner not possible using conventional pumping theory.

5 CONCLUSION

The jet boost pump concept was developed in response to a desire to increase the capacity of existing under-capacity infrastructure, so that remaining asset value is utilised and more cost effective solutions are achieved.

Development testing undertaken at the University of Canterbury has proven the concept and established design theory and parameters. The Dudley Creek culvert boosting application has demonstrated the technology in the field, albeit in a basic arrangement and further research is planned to optimise design method.

The jet boost pump is less hydraulically efficient than a conventional pump but the reduced size and associated flexibility of application can result in significantly lower capital costs to achieve a comparable flow increase.

The jet boost pump is potentially applicable in any piped or open channel system where additional flow capacity is required. It is most hydraulically efficient where flows are less than 2.0m/s and will be economically efficient where the alternate conventional engineering response requires construction of new infrastructure.

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