

Why Adding More Pumps Does Not Always Produce More Flow

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Abstract

Parallel pumping is widely used in water and wastewater infrastructure to provide capacity, operational flexibility and redundancy. A common misconception, however, is that two identical pumps will deliver twice the flow of one pump, three pumps will deliver three times the flow, and four pumps will deliver four times the flow. This is only possible under special conditions and is rarely achieved in a real rising main or distribution system.

When pumps operate in parallel, their flows are added at a common head to form a combined pump curve. The actual station flow is then determined by the intersection of that combined curve with the system curve. Because friction losses generally increase approximately with the square of flow, the system head rises as more water is conveyed. Each additional pump therefore operates at a different point on its own curve and commonly provides a smaller incremental increase in total flow than the pump added before it.

This paper explains the hydraulic principles governing parallel-pump operation, the reasons for diminishing flow returns, the influence of static head and friction, and the risks created by incorrect staging. It also presents a field-assessment methodology informed by Metsiworx's experience with ageing raw-water installations where multiple pumps produced only marginal changes in observed station pressure. The paper argues that pump quantity, control philosophy and replacement strategy must be determined from combined pump and system curves supported by concurrent measurements of flow, total head, speed, power and operating levels.

Keywords: parallel pumps; system curve; pump curve; diminishing flow; raw water; friction loss; pump staging; variable-speed drive; energy efficiency; pump assessment

1. Introduction

Multiple pumps connected to common suction and discharge headers are used throughout raw-water abstraction, potable-water transfer, wastewater

conveyance, treatment works and industrial systems. The arrangement allows output to respond to changing demand and can provide standby capacity when a unit is unavailable.

The operational expectation is often simple: if one pump delivers a particular flow, starting a second identical pump should double it. When site readings show otherwise, the immediate conclusion may be that one or more pumps are defective. Pump wear may indeed be present, but the hydraulic system itself often explains much of the result.

A centrifugal pump does not impose a fixed flow on a system. It produces a relationship between head and flow. The pipe network also has a relationship between required head and flow. The operating point occurs where these two relationships intersect. Starting another pump changes the available combined pump curve, but it also moves the station to a higher-flow condition at which pipe friction is greater. The new operating point is therefore not obtained by multiplying the original flow by the number of pumps.

2. What Parallel Operation Means

Pumps operate in parallel when they draw from a common source or hydraulically connected sources and discharge into a common header. Each pump experiences approximately the same differential head between the common suction and discharge boundaries, although unequal branch losses can create differences.

For identical pumps at the same speed, the ideal combined curve is constructed by adding their flows at the same head:

$$Q_{total}(H) = Q_1(H) + Q_2(H) + \dots + Q_n(H)$$

Thus, if one pump can deliver 100 m³/h at a head of 30 m, two identical pumps could theoretically deliver 200 m³/h at that same 30 m head. This statement describes a point on the combined pump curve; it does not establish the actual operating flow. The system may require substantially more than 30 m at 200 m³/h, in which case the two-pump system will intersect the system curve at a lower total flow and higher head.

Parallel operation should not be confused with series operation. Parallel pumps principally increase flow capability, whereas pumps in series add head at a common flow. In both arrangements, the final duty is governed by interaction with the system curve.

3. The System Curve Controls the Result

For a conventional transfer system, the required head can often be represented approximately as:

$$H_{\text{system}} = H_{\text{static}} + KQ^2$$

Static head represents the elevation and pressure difference between the source and destination boundary conditions. The KQ^2 term represents friction losses in pipes, fittings, valves and equipment. The approximation is useful for turbulent water flow, although a detailed calculation may account for changes in friction factor, branching, control valves and varying boundary pressures.

The consequence is fundamental: doubling the flow can increase the friction component of head by approximately four times. Tripling the flow can increase it by approximately nine times. The pump station must therefore develop more head as its combined flow rises.

In a friction-dominated system with a steep system curve, additional pumps may produce relatively small increases in flow. In a system dominated by static head, where the curve is flatter over the relevant range, parallel pumps can produce a greater increase. The benefit of another pump cannot be judged from pump count alone.

4. Why the Increase Becomes Progressively Smaller

Consider identical centrifugal pumps discharging into the same rising main. One pump operates where its individual curve intersects the system curve. When a second pump starts, the combined pump curve moves to the right because more flow is available at each head. The station operating point also moves to the right and upward along the system curve.

At the higher total flow, each pump sees a higher common head and consequently delivers less than its original single-pump flow. A third pump moves the operating point again, but the system curve is now steeper. The third pump therefore contributes less additional station flow than the second. The same effect becomes more pronounced when a fourth pump is started.

The illustrative curves in Figure 1 show this diminishing return. The example is not site data. It assumes identical constant-speed pumps and a friction-dominated system. Total flow increases from approximately 114 m³/h with one pump to 171 m³/h with two pumps, 194 m³/h with three pumps and 205 m³/h with four pumps. The

incremental additions are therefore approximately 57, 23 and 11 m³/h rather than another 114 m³/h each time.

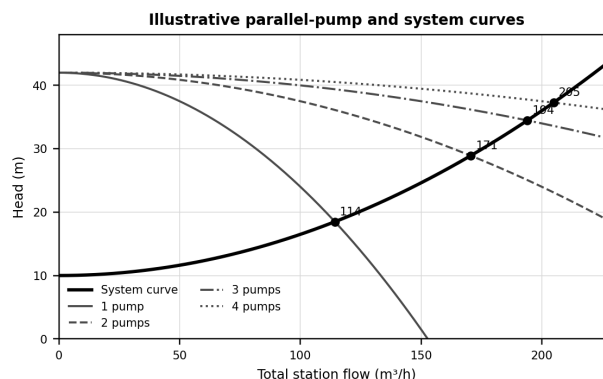


Figure 1. Illustrative diminishing flow increments as parallel pumps are added.

The figure demonstrates why installed pump capacity cannot be added arithmetically without the system curve. It also shows why the energy cost of starting another pump may be substantial even when the hydraulic benefit is small.

5. Lessons from Raw-Water Assessment Experience

During an assessment of an ageing raw-water installation, Metsiworx observed four pumps of unequal motor rating discharging into a common system. Individual pump discharge-pressure readings varied from approximately 67 to 84 kPa. When three pumps operated together, the observed discharge pressure was approximately 92 kPa; with all four pumps operating, it increased only marginally to approximately 94 kPa.

These readings did not, by themselves, establish the flow delivered by each combination. They were discharge-pressure measurements rather than complete pump-total-head measurements, and no verified pump curves or reliable as-built hydraulic information were available. Nevertheless, the small change between three- and four-pump operation was an important diagnostic observation. It demonstrated that starting another motor did not create a proportionate change in the measured hydraulic condition and that the station could not responsibly be evaluated from installed kilowatts or pump quantity alone.

The correct response was to seek the missing system evidence: concurrent flow, suction and discharge conditions, liquid levels, actual rotational speed, electrical input, valve status, pipe configuration and required plant throughput. This is the distinction between recording what an ageing station currently does and determining what it must be redesigned to do.

6. Pressure Alone Can Be Misleading

A small pressure increase after starting another pump does not necessarily mean that the additional pump produces no flow. More water may be moving while friction consumes the additional available head. Conversely, a noticeable pressure increase does not prove that useful delivery has increased if a downstream valve is throttled or the rising main is restricted.

Discharge pressure is also not the same as pump total head. A defensible assessment should include the suction pressure or liquid level, measurement-point elevations and velocity-head corrections:

$$H_{\text{pump}} = (p_d - p_s)/(\rho g) + (v_d^2 - v_s^2)/(2g) + (z_d - z_s)$$

Flow and head must be measured concurrently for every tested pump combination. Without flow measurement, pressure readings can identify a pattern but cannot define the combined pump curve or quantify the contribution of each pump.

7. Additional Causes of Poor Parallel Performance

Diminishing flow caused by the system curve is normal, but site defects and configuration problems can reduce the benefit further.

- **Worn or mismatched pumps:** impeller wear, different impeller diameters, mixed pump models or unequal speeds result in different characteristic curves.
- **Unequal branch losses:** different pipe lengths, bends, valve positions or obstructions prevent identical pumps from sharing flow equally.
- **Non-return-valve problems:** a leaking or slow-closing valve can permit recirculation or reverse flow through an idle pump.
- **Insufficient suction conditions:** falling wet-well or reservoir level, blocked screens, air entrainment, vortices or inadequate NPSH can impair multiple pumps more severely than a single pump.
- **Restricted common main:** internal deposits, a partly closed valve, damaged pipework or an undersized rising main steepen the effective system curve.
- **Incorrect rotation or speed:** a pump can produce some pressure while rotating incorrectly or operating below intended speed.
- **Control-valve interaction:** a pressure- or flow-control valve may close as pumps start, converting additional head into valve loss instead of useful flow.
- **Instrumentation error:** gauge range, blocked pressure tappings, poor flowmeter installation and readings taken at different times can create a false comparison.

8. Risks of Operating Too Many Pumps

Starting every available pump is not necessarily a safe or efficient solution. Potential consequences include:

- High electrical demand with limited additional water delivery.
- Operation of individual pumps at low or unstable flow.
- Operation outside the preferred or allowable operating region.
- Increased vibration, recirculation, bearing load and seal wear.
- Reduced suction level, inadequate submergence and cavitation risk.
- Excessive pipe velocity and surge during starts, stops or valve events.
- Motor overload at portions of the pump curve.
- More frequent failure without meaningful process benefit.

Specific energy consumption provides a useful comparison between combinations:

$$SEC = \text{electrical energy consumed (kWh)} / \text{volume pumped (m}^3\text{)}$$

If adding a fourth pump increases electrical input materially but adds little flow, the kWh/m³ may worsen. The fourth unit may still be justified for a defined emergency condition, but continuous operation would require evidence.

9. A Defensible Field-Test Method

Each pump and each permitted combination should be tested under stable and comparable boundary conditions. The measurement sheet should include:

- Pumps running and confirmed direction of rotation.
- Motor rating, VSD frequency and measured rotational speed.
- Suction level or pressure and discharge pressure.
- Total station flow from a verified flowmeter.
- True three-phase input power, voltage, current and power factor.
- Source and destination water levels or network pressure.
- Valve positions, screen condition and discharge route.
- Vibration, noise, temperature and signs of cavitation.
- Time of reading and process demand.

Tests should normally begin with each pump individually, followed by two-pump, three-pump and four-pump combinations where hydraulically and electrically safe. Readings must be simultaneous or time-synchronised. Changes in reservoir level, abstraction level or

downstream demand must be corrected or the test repeated.

From these results, the assessor can plot measured operating points, compare units, calculate incremental flow and specific energy, and reconstruct the effective system curve. A separate hydraulic calculation using surveyed elevations, pipe diameters, lengths, materials and fittings should be used to cross-check the field curve.

10. Selecting and Staging Parallel Pumps

Good parallel-pump selection begins with the range of required system duties rather than the maximum flow alone. The design should establish minimum, normal, peak and emergency demands; minimum and maximum static head; required redundancy; and future demand separately from present demand.

The combined curves for all intended pump combinations should then be overlaid on the system-curve envelope. Each individual pump's operating point must be checked for efficiency, absorbed power, NPSH required and position within the manufacturer's operating region. It is not enough for the combined curve to cross one nominated duty point.

Where demand varies widely, smaller staged pumps or a combination of fixed- and variable-speed units may provide better coverage than several large identical units. A common strategy is a variable-speed lead pump with additional pumps staged on only when the lead unit approaches an efficient upper operating limit. However, control setpoints, minimum speeds, pump changeover, anti-cycling, minimum run time and failure modes must be engineered for the particular system.

Pumps with different curves can operate in parallel, but their interaction requires special care. If the common header head exceeds the head capability of a weaker pump, that pump may deliver very little flow or be vulnerable to reverse flow. Reliable non-return valves and verified control logic are essential.

11. System Improvements May Outperform Another Pump

When the system curve is excessively steep, reducing resistance may yield more useful flow than installing or starting another pump. Possible interventions include:

- Opening or replacing a restrictive valve.
- Cleaning screens, strainers or fouled pipework.
- Correcting a failed non-return valve.
- Repairing leaks and damaged rising mains.
- Increasing an undersized pipe section.

- Reconfiguring manifolds and high-loss fittings.
- Reviewing control-valve setpoints and unnecessary throttling.
- Addressing air pockets and inadequate air-valve arrangements.

These measures can shift the system curve downward, allowing every operating pump to deliver more flow at lower head and often lower specific energy. Pump replacement should therefore follow diagnosis of the complete system.

12. Information Required from Pump Suppliers

For each proposed selection, the supplier should provide individual and combined performance information for the actual pump model, impeller diameter, speed and liquid.

The submission should include:

- Head-flow, efficiency, absorbed-power and NPSH-required curves.
- Best efficiency point and preferred and allowable operating regions.
- Motor rating and power margin across the complete operating range.
- Minimum continuous flow and application-specific limitations.
- Curves for all intended speeds and pump combinations.
- Materials, impeller details and solids-handling requirements where applicable.
- Control philosophy and staging recommendations.

Commissioning should verify flow, pump total head, speed, electrical input, vibration and control sequencing for the required combinations. These results should become part of the permanent asset record.

13. The Metsiworx Approach

Metsiworx assesses parallel pump installations as integrated hydraulic, mechanical, electrical and control systems. Field observations are combined with measured operating data, reconstructed system conditions and manufacturer performance information before a replacement or staging strategy is recommended.

This approach is particularly important at ageing municipal installations where pump tags, curves, drawings and commissioning records may be missing. It prevents a weak diagnosis from becoming the design basis for another generation of equipment and allows the client to distinguish among pump deterioration, system

resistance, control limitations and changing process demand.

14. Conclusion

Adding more centrifugal pumps in parallel increases the available combined flow at a given head, but it does not multiply the actual station flow in direct proportion to pump count. The operating point is determined by the intersection of the combined pump curve and the system curve. As flow rises, friction losses rise rapidly, and each additional pump commonly produces a smaller incremental benefit.

The engineering question is therefore not simply how many pumps are running. It is how each pump interacts with the common hydraulic system across all required operating conditions. Concurrent measurement of flow, total head, speed, power and levels is essential, particularly where the original records are missing.

Parallel pumping can provide excellent flexibility, efficiency and resilience when correctly selected and controlled. When it is poorly understood, it can lead to high energy consumption, disappointing flow, unstable operation and repeated equipment failure. The solution lies in measuring the system, constructing the curves and selecting the station as a complete operating system rather than as a collection of individual pumps.

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