# FRESH WATER AND WASTEWATER MINIMIZATION: CONCEPTS, SOFTWARE AND RESULTS

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## Introduction

Increasing environmental awareness and rising treatment costs have led to growing pressure on process plant operators to reduce raw water consumption and wastewater discharges. In this paper we illustrate systematic approaches to minimizing fresh water demand and wastewater generation by maximizing the re-use of water within processes. Over eleven industrial applications have been completed using these approaches. Typical reductions in fresh water usage and wastewater discharges identified are between 30% and 50%, coupled with significant reduction in capital investment in treatment facilities. This paper describes the concepts underlying the new approaches and describes results from an industrial application.

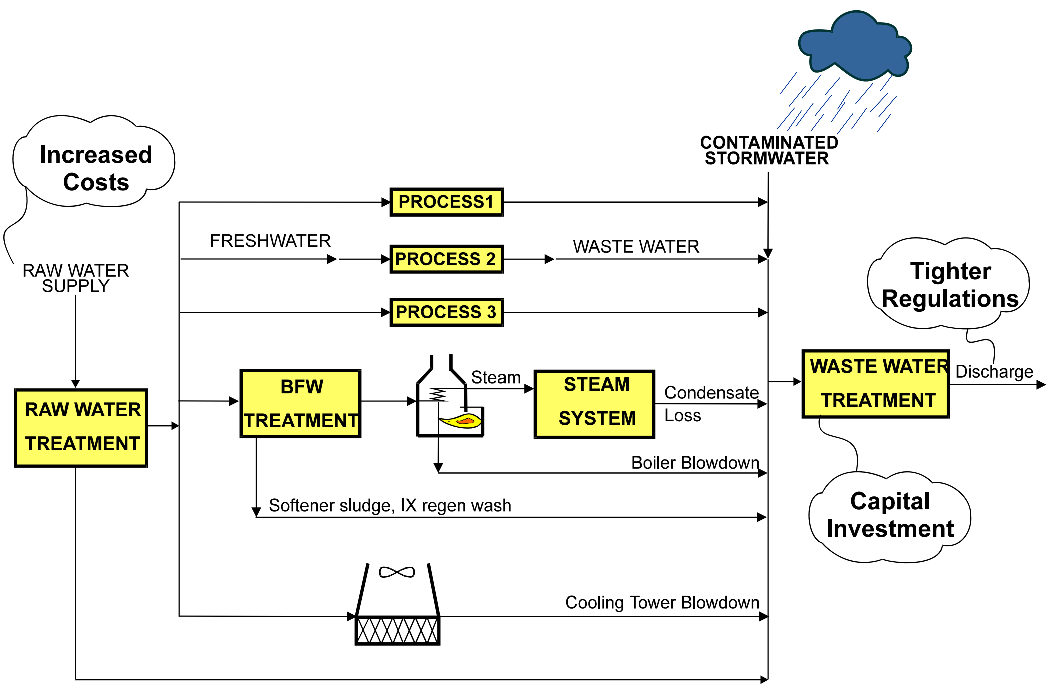



**Figure 1**: **Typical water network in the process industries**

Figure 1 shows a typical water network in a process plant or site. After initial raw water treatment, the incoming water is used to meet process requirements and to supply the utility system (steam and cooling water). Wastewater from the processes along with blowdowns and condensate losses from the utility system are usually collected together and treated in a central waste-water treatment facility prior to discharge.

Aquifers are being depleted, fresh water supply from rivers and lakes is diminishing and discharge regulations are getting tighter. As a result, the costs of fresh water and wastewater treatment are rising and companies are increasingly being forced to consider expensive new or expanded treatment facilities. These factors are the main driving forces for minimizing fresh water demand and wastewater generation.

## Systematic Approaches to Water Minimization

In general, water demand can be reduced by improving efficiency within the individual unit operations or by increasing re-use of water among process and utility system water users.

Process unit operation improvements : These involve changes in the unit operations to reduce the inherent water demand, for example, replacing water cooling with air cooling, improving controls of boiler and cooling tower blowdowns, increasing the number of extraction stages to reduce the water demand etc.

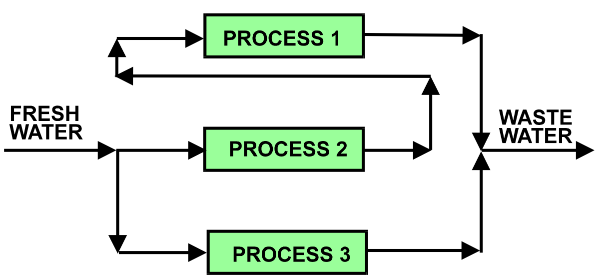



**Figure 2(a): Direct water reuse**

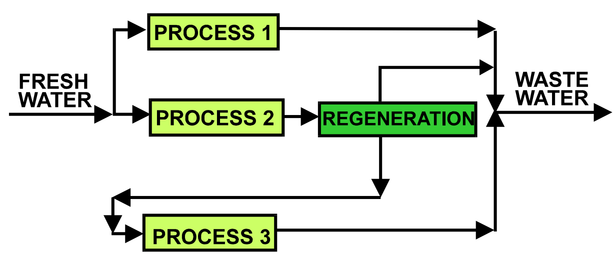



**Figure 2(b): Water reuse after regeneration**

Water re-use : This implies using the outlet water from one operation to satisfy the water requirement of another or same operation. In some cases the water may require partial treatment (regeneration) prior to re-use. Figure 2 illustrates two main options for re-use.

*Direct re-use*: The outlet water from one unit operation can be directly re-used to satisfy the water demand of another operation as shown in figure 2(a). The outlet water is sufficiently clean for the next operation.

*Regeneration re-use*: The outlet water from a process unit is treated sufficiently to make it suitable for use in one or more of the water-consuming operations as shown in figure 2(b). Partial treatment, for the purpose of rendering the wastewater suitable for reuse, is called regeneration. There are many different types of regeneration. Regeneration could imply something as simple as pH adjustment or physical removal of unwanted impurities e.g. by filters, membrane separators, sour water strippers, ion exchange systems, etc.

*Regeneration recycle: In* some cases the regenerated water may be suitable for re-use within the same operation from whence it once came. This is called recycling. Water recycle carries with it the risk of potential build-up of trace contaminants in the process, which must be addressed before deciding to do so.

Traditionally fresh water use and wastewater generation have been reduced by considering design improvements in individual unit operations or by identifying water re-use opportunities across unit operations *without systematic consideration of the overall process or the total site implications*.

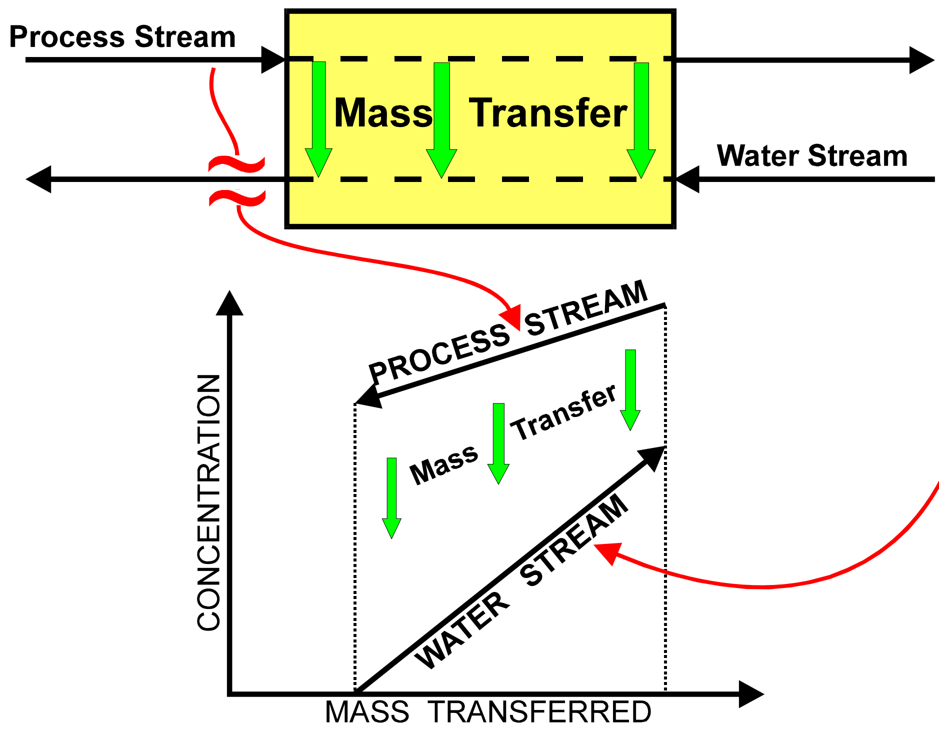
Recently, systematic approaches have been developed to maximize re-use of water within processes or sites [2,3,4]. In this paper we will review these approaches and describe new developments that have emerged from several industrial applications. All the systematic approaches include elements of Pinch Analysis [1].

***Mass Transfer Based Approaches***

Pinch Analysis was originally developed as a method to solve complex multi-stream heat integration problems by converting stream data into a visual representation on temperature / enthalpy axes. Since there are parallels between the principles of heat transfer and mass transfer, the established principles of thermal pinch analysis can be extended to the wastewater minimization problem [2,3].

El-Halwagi and Manousiouthakis (1989) addressed a more general problem of mass exchange between a set of rich process streams and a set of lean streams. Wang and Smith (1994) specifically addressed the water minimization problem by considering it as a contamination transfer problem from process streams to water streams. Both these approaches are based on the model of a process unit as a mass transfer unit, as illustrated in figure 3. Contaminant is transferred from the rich process stream to the water stream. Concentration differences provide the driving force for mass transfer between the process stream and the water stream as indicated by the gap between the process and water stream profiles on concentration/mass axes.

We will review the approach developed by Wang and Smith (1994) in more detail. As a first step, a limiting water profile is set for each water using process operation. This is based on maximum permissible inlet and outlet concentrations for the water stream for each operation.



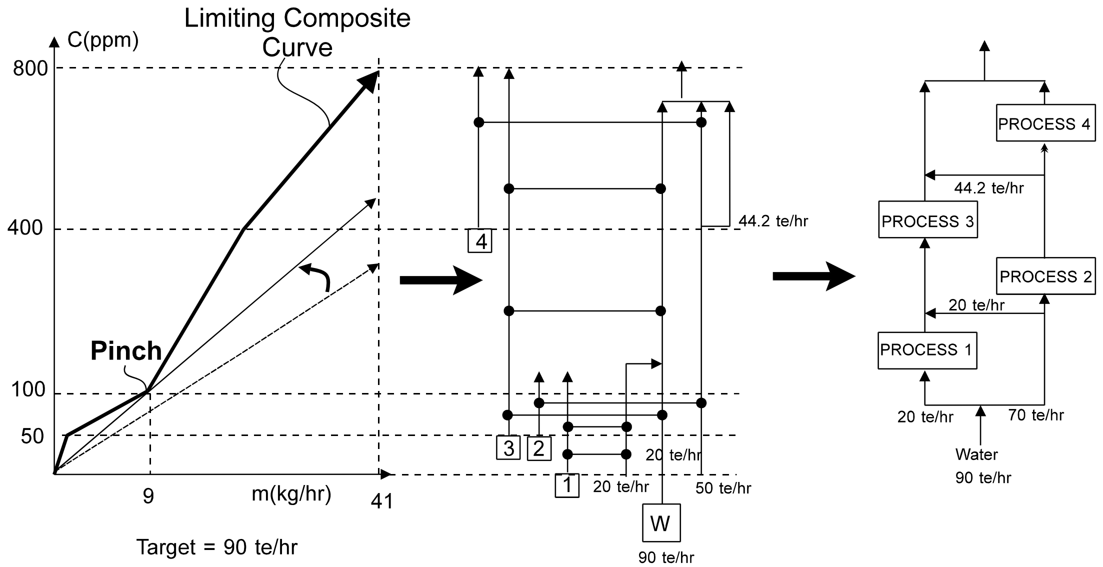

**<u>Figure 3</u>: Mass transfer model for water-using operation**

Figure 4 summarizes the remaining steps in the approach. The limiting water stream concentrations of all the process units are combined together to construct the limiting composite curve for the overall plant as in figure 4(a). The fresh water line is then matched against the limiting composite curve to set the minimum fresh water demand for the overall plant. The minimum fresh water line touches the limiting composite curve both at zero concentration and at an intermediate point (denoted as "pinch point"). This corresponds to the minimum fresh water flowrate required for the plant and is set as a "target" corresponding to maximizing re-use.

The limiting composite curve construction also shows critical sections of the plant (region close to pinch concentration) that requires close attention in order to achieve the minimum water requirement.

In order to develop the water piping network that provides the minimum water demand, the approach uses network design methodology analogous to the pinch design method [1] as shown in figure 4(b). The initial networks obtained tend to have complex structures. These are then simplified to obtain a practical network as shown in figure 4(c) using an evolutionary procedure.

The explanation so far involves only one contaminant. The construction of the limiting composite curves and network design becomes more complex when there are multiple contaminants [3].




*(a) Limiting composite curve for setting minimum water target*

*(b) Pinch design grid*

*(C) Conventional flowsheet for simplified design after evolution*

**<u>Figure 4:</u> Wang and Smith (1994) approach for water minimization**

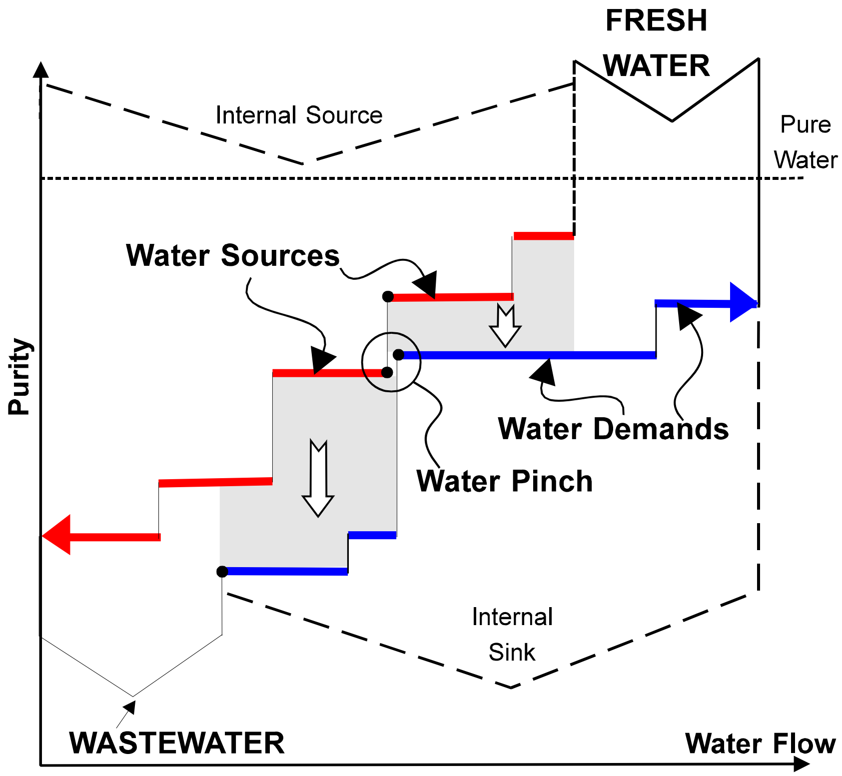
The Wang and Smith approach uses contaminant mass transfer as a basic process model. Unfortunately, there are many process units such as reactors, boilers, and cooling towers which do not fit this model. For example, several water based streams may enter and leave the process unit at different concentrations. There could be water loss due to evaporation, or gain due to reaction. Also, practical constraints cannot be addressed, such as geographical distances (long pipe work) and other constraints that may forbid re-use of water from one unit to another.

Despite these difficulties, the Wang and Smith method represents the first systematic approach to designing a "total system" for minimum water use.

Linnhoff March has used this approach on its initial pioneering projects. Based on this project experience we have now developed a more convenient and powerful alternative methodology for wastewater minimization called the WaterPinch™ approach [6].

### *New WaterPinch Approach*

The WaterPinch approach uses two main tools, a new graphical construction for visualization and rapid screening of design options used in conjunction with a mathematical optimization algorithm for detailed quantification of results. This approach overcomes many of the problems outlined above and in addition satisfies some of the other practical issues encountered in a water minimization project.



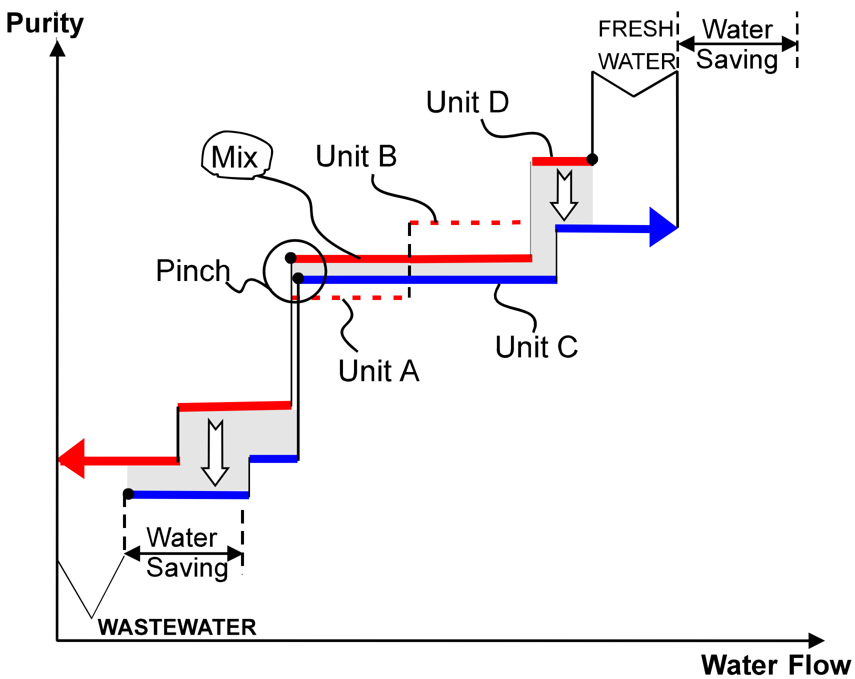

**<u>Figure 5:</u> WaterPinch approach : basic representation**

Figure 5 shows the basic representation used in the WaterPinch approach, which is similar in concept to the composite curves used in energy pinch analysis [1]. Water purity is plotted on the vertical axis and water flowrate on the horizontal axis. Each water related process operation can be considered as having input and output water streams. There can be several input and output water streams at different purities for a single operation. The input water streams of all the water using operations are plotted in a "demand composite" form to define the water demand for the overall plant as shown in figure 5. Similarly the output water streams of all the operations are plotted to construct the "source composite" for the plant. The major difference is that the Wang and Smith approach has a unit operations focus, whereas the new WaterPinch approach has a stream focus.

The overlap between the source and the demand composite (shown by shaded area) indicates scope for water re-use. The available overlap is limited by the "pinch point" between the source and the demand composite. The representation in figure 5 also identifies minimum fresh water demand and minimum wastewater generation without water mixing (as we will see later).

The representation also guides the designer to identify specific design changes that will enable increased re-use of water. Figure 6 shows an example. By mixing water sources from units A and B we generate a mixture of intermediate purity (shown as "Mix"). This relieves the existing pinch point bottleneck, allowing greater overlap of the source and demand composites and increasing the overall water recovery in the process. The

WaterPinch representation also simultaneously provides the design guidelines as shown in figure 6. For example, the representation indicates that the water mixture from outlets of units A and B needs to supply water to unit C. The remaining water demand for unit C can be satisfied by part of the water outlet from unit D. The WaterPinch™ approach therefore not only sets the targets, but also suggests appropriate network design changes which maximize the re-use of water.



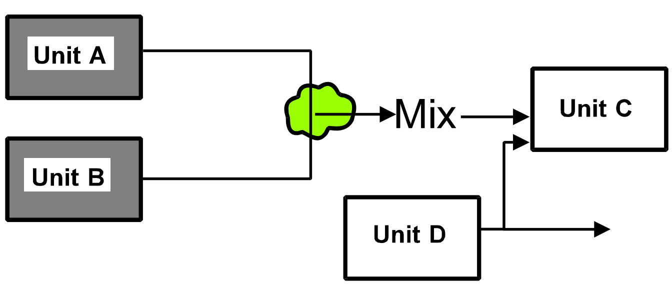
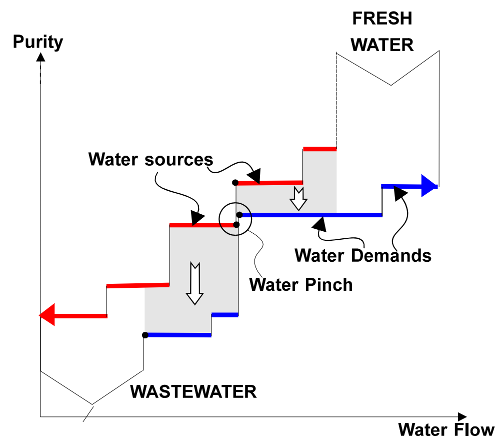




**Figure 6: Combined targeting and design using WaterPinch approach**
**(a) Composite Curves (b) Flowsheet representation**




**Mathematical Optimization**

- Compare key design options
- Understand critical regions

**SWITCH**

- Multicomponent systems
- Practical design

**<u>Figure 7:</u> Visual and quantitative tools are fully compatible**

The visual representations as shown in figures 5 and 6 can also be implemented in an equivalent mathematical form. The mathematical optimization approach is completely compatible with the visual representation. The user can switch between mathematical and visual modes at any stage.

The mathematical tool, involving a mixed-integer non-linear programming algorithm, allows the user to handle complex water networks with ease. For example, systems with multiple contaminants and large number of operations can be analyzed in a reliable quantitative manner. For large problems the user may find it easier to start with the mathematical tool and visualize the simplified solutions.

The use of the mathematical tool also permits the consideration of practical issues such as geographical and operability constraints or different costs of fresh waters and costs of treatment etc.

To summarize, the WaterPinch approach is based on a flexible definition for a water using operation. The operation can have multiple water inlets and outlets all at different purities. The approach uses a combination of visual and mathematical tools which provides a balance between engineering insights and reliable quantitative results. The visual tool directly provides design guidelines while the mathematical tool is able to automatically generate the optimal designs. The approach also provides specific guidelines for suggesting appropriate regeneration options [6].

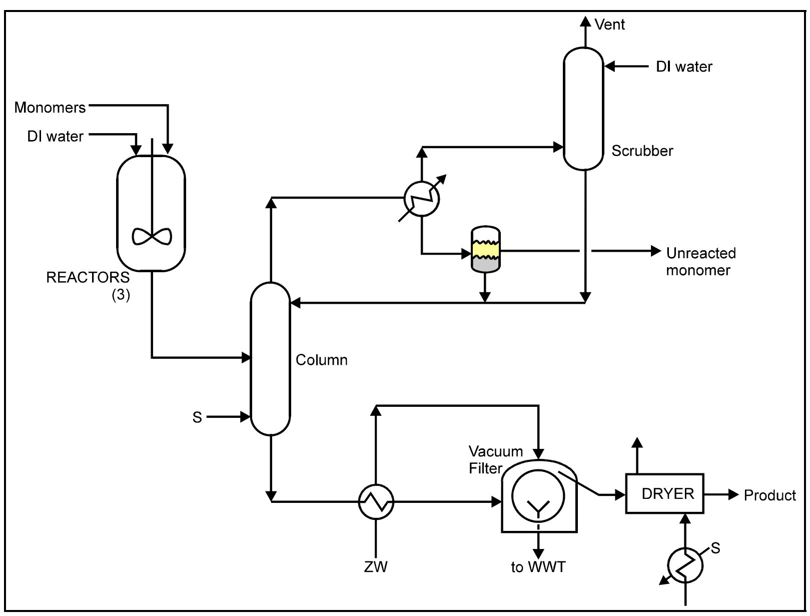
## Industrial Case Study

We will now discuss results from one of our industrial water minimization projects. This case study will cover the techniques, mechanics, software and thought processes employed to minimize wastewater at a chemicals manufacturing complex in the southeastern US. Each water minimization problem requires not only a thorough knowledge of the client's needs and budget constraints, but also the processes and their interactions, and the current and pending environmental regulations.

This facility had several major process units, all of which consumed some fresh water and generated wastewater. The wastewater treatment plant at this facility was at the limit of its hydraulic capacity. With tighter environmental restrictions on the horizon and a production expansion plan of 30% over the next five years, an expansion in the water treatment plant was almost certain to be required, at an estimated cost of over $3MM. The fresh water supply was plentiful, and was considered to be free.

The plant wanted to reduce wastewater flow by 25%. This would permit the existing wastewater treatment facility to meet expected future loads and save $3MM in avoided capital cost. The WaterPinch approach was expected to reduce wastewater flow through reuse and regeneration, at a total cost not to exceed $1MM.

To illustrate the methodology, we shall confine our attention to just one of the process units on site, viz. polymer manufacturing. Figure 8 shows a simplified process flowsheet.




**<u>Figure 8:</u> Polymer Manufacturing Process**

The first step is to identify all the water sources (effluent) and sinks (users). For this process, there is only one source, the vacuum filter effluent and the sinks are the reactor, scrubber, stripping steam and vacuum filter cake wash. So our “data extraction” would give us:

| Stream ID | Flow, gpm | Comments |
|---|---|---|
| Reactor dilution water | 185 | need DI |
| Scrubber wash water | 6 | using DI; switch to ZW ? |
| Vacuum filter cake wash | 260 | need ZW |
| Vacuum filter effluent | 489 | has SS, toxic organics |

We now start looking for possibilities to reduce water use. Based on the foregoing fixed process requirements, there are no obvious opportunities for water reuse. One possibility for consideration could be multistage filter cake washing, but this would be very expensive. The vacuum filter effluent is unsuitable for reuse because of unreacted monomer which is toxic, and suspended polymer particles which could plug up downstream equipment. It may look like the process cannot be improved, but appearances can be deceptive. The WaterPinch approach provides a systematic way to determine conservation potential.

### *Step 1- Consider The Entire Water system, Not Just The Process*

Draw out the complete water system flowsheet, as in Figure 9. All of the water that enters or leaves the plant must be identified.

### *Step 2-Develop A Total Plant Water Balance*

Make sure that the sum of individual water users agrees with the metered water intake. Similarly, the sum of the identified effluents must be equal to the measured flow to the wastewater treatment plant. If the differences are less than 10%, then we accept the balance. If the difference is greater than 10%, we have to look for non-obvious sources and sinks. It is not essential that city water in is equal to wastewater out because of water losses from cooling tower evaporation, reaction effects, vapor vents and water gains, e.g., storm water. The important accounting check is that the sum of the sinks equal the metered inflow and the sum of the sources equal the metered outflow.

After a number of trial balances the final plant water balance gave good agreement. See Table 1.

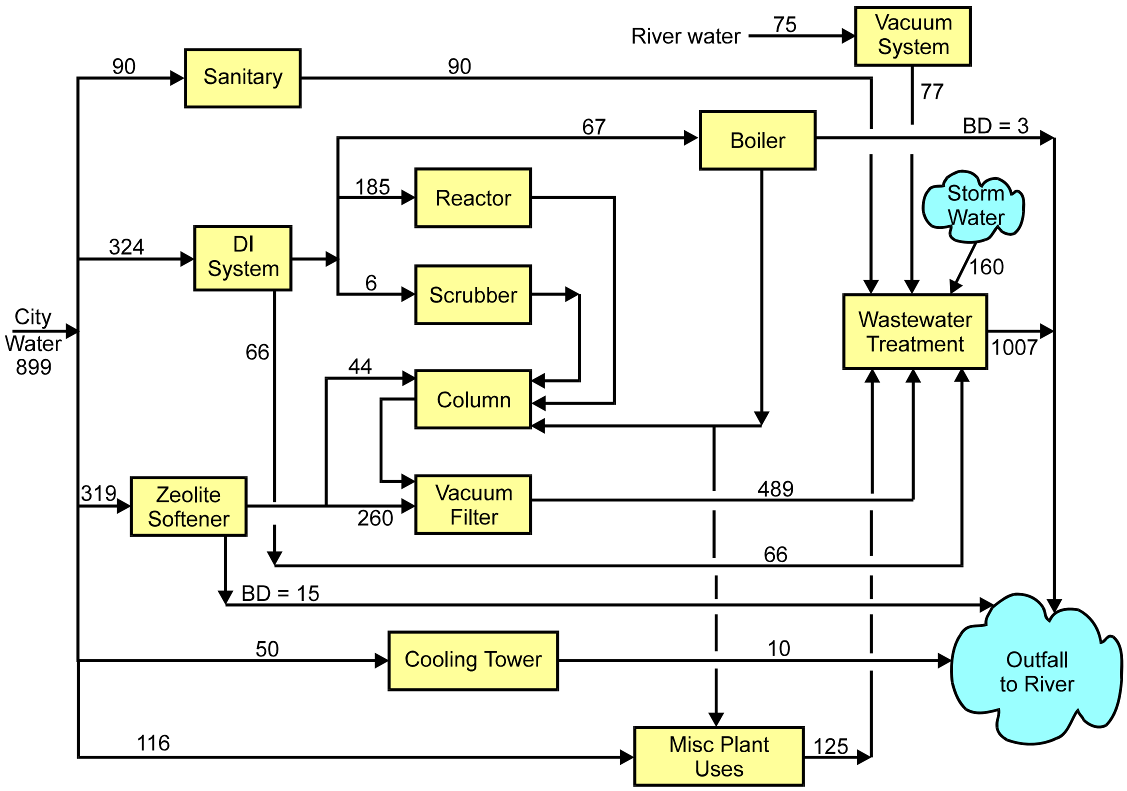



**Figure 10: Schematic Flowsheet and Water Balance**

## *Step 3-Data Extraction*

The next step in the pinch analysis process is data extraction. Here we must select the streams and identify the key contaminants. The key contaminants are those which render the effluent water unfit for reuse. The "In" streams include those where we are prepared to use alternate sources of water. The "Out" streams are those which are currently going to wastewater treatment. The rationale for including or excluding streams in the pinch analysis is summarized in Table 2.

Now we must choose the key contaminants. But how? Let's start off simply, with just three:

- Organics (BOD)
- Salts (Conductivity)
- Suspended solids.

Other potential contaminants can be added later such as specific toxins, pH, and temperature. We now have our preliminary stream data for the existing process, per Table 3.

| | | Consumption, gpm | | | | Production, gpm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Process/Equipment** | **Stream ID** | CW | ZW | DI | Other | ZW | DI | Other | WWT | Outfall | | |
| | | | | | | | | | | | | |
| Zeolite Softener | Feedwater | 304 | | | | | | | | | | |
| | Rinse water | 15 | | | | | | | | | | |
| | Spent backwash | | | | | | | | | 15 | | |
| | Softened water | | | | | 304 | | | | | | |
| | Subtotal | 319 | 0 | 0 | 0 | 304 | 0 | 0 | 0 | 15 | Difference | 0 |
| | | | | | | | | | | | | |
| Demin System | Feedwater | 268 | | | | | | | | | | |
| | Acid rinse | 16 | | | | | | | | | | |
| | Acid spent wash | | | | | | | | 16 | | | |
| | Caustic rinse | 40 | | | | | | | | | | |
| | Caustic spent wash | | | | | | | | 40 | | | |
| | Test meter bypass | | | 10 | | | | | 10 | | | |
| | Product DI water | | | | | | 268 | | | | | |
| | Subtotal | 324 | 0 | 10 | 0 | 0 | 268 | 0 | 66 | 0 | Difference | 5.68E-14 |
| | | | | | | | | | | | | |
| Process (direct) | Reactor dilution water | | | 185 | | | | | | | | |
| | Column steam | | | | 50 | | | | | | | |
| | Scrubber wash | | | 6 | | | | | | | | |
| | Filter cake wash | | 260 | | | | | | | | | |
| | Product | | | | | | | 56 | | | | |
| | Vac Filter effluent | | | | | | | | 489 | | | |
| | Subtotal | 0 | 260 | 191 | 50 | 0 | 0 | 56 | 489 | 0 | Difference | -44 |
| | | | | | | | | | | | | |
| Process (indirect) | Column tray flush | | 7 | | | | | | | | | |
| | Column spray nozzles | | 12 | | | | | | | | | |
| | Water to column feed | | 25 | | | | | | | | | |
| | Vac jet steam | | | | 2 | | | | | | | |
| | Vac jet barom condenser | | | | 75 | | | | 77 | | | |
| | Pump seals | 43 | | | | | | | 43 | | | |
| | Pump hosedown | 5 | | | | | | | 5 | | | |
| | Dryer wash down | 42 | | | | | | | 42 | | | |
| | Dryer exhaust vapor | | | | 53 | | | 53 | | | | |
| | Satety shower trips | 6 | | | | | | | 6 | | | |
| | Unrecov'd stm condensate | | | | 8 | | | | 8 | | | |
| | Floor washing | 20 | | | | | | | 20 | | | |
| | Subtotal | 116 | 44 | 0 | 139 | 0 | 0 | 53 | 202 | 0 | Difference | 44 |
| | | | | | | | | | | | | |
| Boiler | Feedwater makeup | | | 67 | | | | | | | | |
| | Condensate return | | | | 45 | | | | | | | |
| | Steam | | | | | | | 108 | | | | |
| | Blowdown | | | | | | | | | 3 | | |
| | Subtotal | 0 | 0 | 67 | 45 | 0 | 0 | 108 | 0 | 3 | Difference | 1.42E-14 |
| | | | | | | | | | | | | |
| Cooling Tower | Makeup | 50 | | | | | | | | | | |
| | Evap loss | | | | | | | 40 | | | | |
| | Blowdown | | | | | | | | | 10 | | |
| | Subtotal | 50 | 0 | 0 | 0 | 0 | 0 | 40 | 0 | 10 | Difference | 0 |
| | | | | | | | | | | | | |
| Other | Storm water | | | | 160 | | | | 160 | | | |
| | Sanitary users | 90 | | | | | | | | | | |
| | Sanitary sewer | | | | | | | | 90 | | | |
| | Subtotal | 90 | 0 | 0 | 160 | 0 | 0 | 0 | 250 | 0 | Difference | 0 |
| | | | | | | | | | | | | |
| SITEWIDE TOTALS | | 899 | 304 | 268 | 394 | 304 | 268 | 257 | 1007 | 28 | Difference | 0 |
| METERED FLOWS | | 900 | 300 | 260 | | | | | 1000 | | | |
| DIFFERENCE, % | | 0 | -1 | -3 | | | | | -1 | | | |

## Table 1: Plant Water Balance

| **Stream Description** | **Comment** |
|---|---|
| 1. Feedwater to zeolite system | No, because it is the supply for another utility. |
| 2. Zeolite system backwash | Yes. |
| 3. Spent Brine | No, because it does not go to WWT. |
| 4. Softened Water | No, treat it as a utility source. |
| 5. Demin system feedwater | No, because it is a supply for another utility. |
| 6. Product DI water | No, treat it as a utility source. |
| 7. Column Steam | Depends on process constraints:<br>a) No, if reboiler is permitted.<br>b) Yes, if vaporizer is required. |
| 8. Pump Seals | Depends:<br>Seal water consumption counts in all cases<br>Seal water counts only if it is easily collectable; it does not count if it drains to sewer and ends up in the sump. |
| 9. Dryer Exhaust Vapor | No, needs capital and there are no net water savings if the heat sink is the cooling tower. |
| 10. Safety shower trips | Depends:<br>a) Consumption included, but provide city water specs.<br>b) Discharge included separately if collectable.<br>c) Discharge included with sump if <u>not</u> collectable. |
| 11. Unrecovered steam condensate | No, it's not easily collectable, included in sump flow. |
| 12. Boiler FW makeup | Yes. |
| 13. Boiler Blowdown | Depends:<br>a) Yes for fresh water conservation objective.<br>b) No for wastewater minimization objective because it does not go to WWT. |
| 14. Cooling tower makeup | Yes. |
| 15. Cooling tower blowdown | Depends: Same as boiler blowdown. |

**<u>Table 2</u>: Data Extraction Principles**

| | | Flow, gpm | | Actual Conc, ppm | | |
|---|---|---|---|---|---|---|
| **Process/Equipment** | **Stream ID** | In | Out | Org | Salts | SS |
| | | | | | | |
| Zeolite Softener | Backwash | 15.2 | | 1 | 150 | 5 |
| | | | | | | |
| Demin System | Acid rinse | 16.1 | | 1 | 150 | 5 |
| | Acid spent wash | | 16.1 | 1 | 16405 | 300 |
| | Caustic rinse | 40.1 | | 1 | 150 | 5 |
| | Caustic spent wash | | 40.1 | 1 | 19058 | 300 |
| | Test meter bypass | 10 | 10 | 1 | 12 | 1 |
| | | | | | | |
| Process (direct) | Reactor dilution water | 185 | | 1 | 12 | 1 |
| | Vaporizer feed | 50 | | 1 | 12 | 1 |
| | Scrubber wash | 6 | | 1 | 12 | 1 |
| | Filter cake wash | 260 | | 1 | 147 | 1 |
| | Vac Filter effluent | | 489 | 26 | 1680 | 250 |
| | | | | | | |
| Process (indirect) | Column tray flush | 7 | | 1 | 147 | 1 |
| | Column spray nozzles | 12 | | 1 | 147 | 1 |
| | Water to column feed | 25 | | 1 | 147 | 1 |
| | Vac jet barom condenser | 75 | | 50 | 150 | 100 |
| | Vac jet hot well | | 77.3 | 60 | 150 | 100 |
| | Pump seals in | 43 | | 1 | 150 | 5 |
| | Pump seals out | | 43 | 20 | 150 | 5 |
| | Pump hosedown | 5 | | 1 | 150 | 5 |
| | Dryer wash down | 42 | | 1 | 150 | 5 |
| | Satety shower trips | 6 | | 1 | 150 | 5 |
| | Floor washing | 20 | | 1 | 150 | 5 |
| | Area sump | | 73.3 | 50 | 1800 | 400 |
| | | | | | | |
| Boiler | Feedwater makeup | 66.6 | | 1 | 12 | 1 |
| | | | | | | |
| Cooling Tower | Makeup | 50 | | 1 | 150 | 5 |
| | | | | | | |
| Other | Storm water | | 160 | 50 | 100 | 300 |
| | Sanitary users | 90 | | 1 | 150 | 5 |
| | Sanitary sewer | | 90 | 60 | 400 | 1200 |
| | | | | | | |
| Utility Sources | Softened water | | 350 | 1 | 147 | 1 |
| | Product DI water | | 350 | 1 | 12 | 1 |
| | City Water | | 1000 | 1 | 150 | 5 |

**Table 3: Initial Stream Data**

***Step 4-Run WaterPinch software to obtain initial water reuse strategy***
The targets obtained by running the data in Table 3 are:

| | gpm |
|---|---|
| City Water | 325 |
| Zeolite Water | 304 |
| DI Water | 308 |
| Wastewater | 920 |

The reuse strategy given by the software was:

| # | Source ID | Sink ID | Savings, gpm | | | | |
|---|---|---|---|---|---|---|---|
| | | | DI | ZW | CW | RW | WW |
| 1 | Vac jet hot well | Vac jet barom cond | - | - | - | 32 | 32 |
| 2 | Pump seals | Vac jet barom cond | - | - | - | 43 | 43 |
| 3 | Test meter | BFW makeup | 10 | - | - | - | 10 |
| | | Totals | 10 | 0 | 0 | 75 | 85 |

While this strategy may look good on paper, a more detailed consideration showed several practical problems.

- Project 1 is not feasible because the hot well temperature is too high to use in the barometric condenser. Further, if it were cool enough, there would still be a problem with the buildup of contaminants. There is no way for the software to know such things.
- Project 2 is not feasible because the pump seal water "out" is too hot to use in the barometric condenser.
- Project 3 looks good.

After rejecting projects 1 and 2, the savings potential is pitifully low. The reason for this is that we are forcing the software to use the same high quality of water as the current operation. We must relax the design concentration specifications for the "In" and "Out" streams based upon judgment, as follows:

- $C_{IN}$ = maximum allowable, and
- $C_{OUT}$ = a) the desired target, or
  b) the expected value based on equilibrium or the heat and material balance

The adjusted stream data are shown in Table 4. Now, we run WaterPinch again, and obtain a more realistic projects list:

| # | Source ID | Sink ID | Savings, gpm | | | | |
|---|---|---|---|---|---|---|---|
| | | | DI | ZW | CW | RW | WW |
| 1 | Vac filtrate | Column tray flush | - | 7 | - | - | 7 |
| 2 | Vac filtrate | Column feed | - | 25 | - | - | 25 |
| 3 | Vac filtrate | Vac jet barom cond | - | - | - | 75 | 75 |
| 4 | Vac filtrate | Pump seals in | - | - | 28 | - | 28 |
| 5 | Vac filtrate | Dryer washdown | - | - | 42 | - | 42 |
| 6 | Vac filtrate | Floor washing | - | - | 20 | - | 20 |
| 7 | Vac filtrate | Vaporizer feed | 9 | - | - | - | 9 |
| 8 | Pump seals out | Vaporizer feed | 41 | - | - | - | 41 |
| 9 | Test meter | BFW makeup | 10 | - | - | - | 10 |
| | | | 60 | 32 | 90 | 75 | 257 |

Let us evaluate the revised projects critically:

- Projects 1 and 2 look good.
- Project 3: Temperature problem.
- Project 4: Vacuum filtrate is mixed with city water in a 2-to-1 ratio. It meets the concentration criteria, but what about temperature?
- Projects 5 and 6: Can’t do. High temperature is good, but there is a problem with toxics.
- projects 7,8, and 9 look good.

Now we can identify temperature and toxics as new quality parameters. One way to include their effects is to add them as new “key contaminants”. Alternately, we could impose constraints forbidding the use of known hot streams for vacuum jet barometric condenser use, and the use of known toxic streams where human exposure is a possibility.

The savings potential is now better than before, but we still have a long way to go.

| | | Flow, gpm | | Actual Conc, ppm | | | Design Conc, ppm | | |
|---|---|---|---|---|---|---|---|---|---|
| **Process/Equipment** | **Stream ID** | In | Out | Org | Salts | SS | Org | Salts | SS |
| | | | | | | | | | |
| Zeolite Softener | Backwash | 15.2 | | 1 | 150 | 5 | 1 | 150 | 5 |
| | | | | | | | | | |
| Demin System | Acid rinse | 16.1 | | 1 | 150 | 5 | 1 | 150 | 5 |
| | Acid spent wash | | 16.1 | 1 | 16400 | 300 | 1 | 16400 | 300 |
| | Caustic rinse | 40.1 | | 1 | 150 | 5 | 1 | 150 | 5 |
| | Caustic spent wash | | 40.1 | 1 | 19060 | 300 | 1 | 19060 | 300 |
| | Test meter in | 10 | | 1 | 12 | 1 | 1 | 12 | 1 |
| | Test meter out | | 10 | 1 | 12 | 1 | 1 | 12 | 1 |
| | | | | | | | | | |
| Process (direct) | Reactor dilution water | 185 | | 1 | 12 | 1 | 1 | 12 | 1 |
| | Vaporizer Feed | 50 | | 1 | 12 | 1 | 100 | 3000 | 300 |
| | Scrubber wash | 6 | | 1 | 12 | 1 | 1 | 150 | 10 |
| | Filter cake wash | 260 | | 1 | 147 | 1 | 1 | 147 | 1 |
| | Vac Filter effluent | | 489 | 26 | 1680 | 250 | 30 | 1800 | 300 |
| | | | | | | | | | |
| Process (indirect) | Column tray flush | 7 | | 1 | 147 | 1 | 30 | 1800 | 300 |
| | Column spray nozzles | 12 | | 1 | 147 | 1 | 1 | 147 | 1 |
| | Water to column feed | 25 | | 1 | 147 | 1 | 30 | 1800 | 300 |
| | Vac jet barom condenser | 75 | | 50 | 150 | 100 | 50 | 1800 | 300 |
| | Vac jet hot well | | 77.3 | 60 | 150 | 100 | 200 | 3000 | 500 |
| | Pump seals in | 43 | | 1 | 150 | 5 | 30 | 1800 | 200 |
| | Pump seals out | | 43 | 20 | 150 | 5 | 50 | 1800 | 200 |
| | Pump hosedown | 5 | | 1 | 150 | 5 | 50 | 1800 | 300 |
| | Dryer wash down | 42 | | 1 | 150 | 5 | 50 | 1800 | 300 |
| | Satety shower trips | 6 | | 1 | 150 | 5 | 1 | 150 | 5 |
| | Floor washing | 20 | | 1 | 150 | 5 | 30 | 1800 | 300 |
| | Area sump | | 73.3 | 50 | 1800 | 400 | 100 | 3500 | 700 |
| | | | | | | | | | |
| Boiler | Feedwater makeup | 66.6 | | 1 | 12 | 1 | 1 | 12 | 1 |
| | | | | | | | | | |
| Cooling Tower | Makeup | 50 | | 1 | 150 | 5 | 20 | 200 | 30 |
| | | | | | | | | | |
| Other | Storm water | | 160 | 50 | 100 | 300 | 50 | 100 | 300 |
| | Sanitary users | 90 | | 1 | 150 | 5 | 1 | 150 | 5 |
| | Sanitary sewer | | 90 | 60 | 400 | 1200 | 200 | 1000 | 1500 |
| | | | | | | | | | |
| Utility Sources | Softened water | | 350 | 1 | 147 | 1 | 1 | 147 | 1 |
| | Product DI water | | 350 | 1 | 12 | 1 | 1 | 12 | 1 |
| | City Water | | 1000 | 1 | 150 | 5 | 1 | 150 | 5 |

**Table 4: Adjusted Stream Data**

### *Step 5-Identify Pinches*

Pinches are defined as contaminant concentrations, which if changed, would permit greater water reuse. In general, we relieve the pinch by increasing the maximum allowable inlet concentration (to sinks) and decreasing the outlet concentration from sources. We may not have the freedom to arbitrarily specify lower values of $C_{OUT}$, however, as this is governed by process chemistry and the laws of physics.

The WaterPinch software identifies the key pinch concentrations for us, in the form of 3-D sensitivity charts, per figures 10& 11. Now the question is, can we really tolerate higher inlet concentrations for the pinch streams? Let us consider them one by one.

- Salts in reactor dilution water No
- SS in vacuum filter wash No
- Organics in sanitary water No
- Organics in pump seal water Maybe
- Etc.

### *Step 6-Identify potential beneficial process modifications*

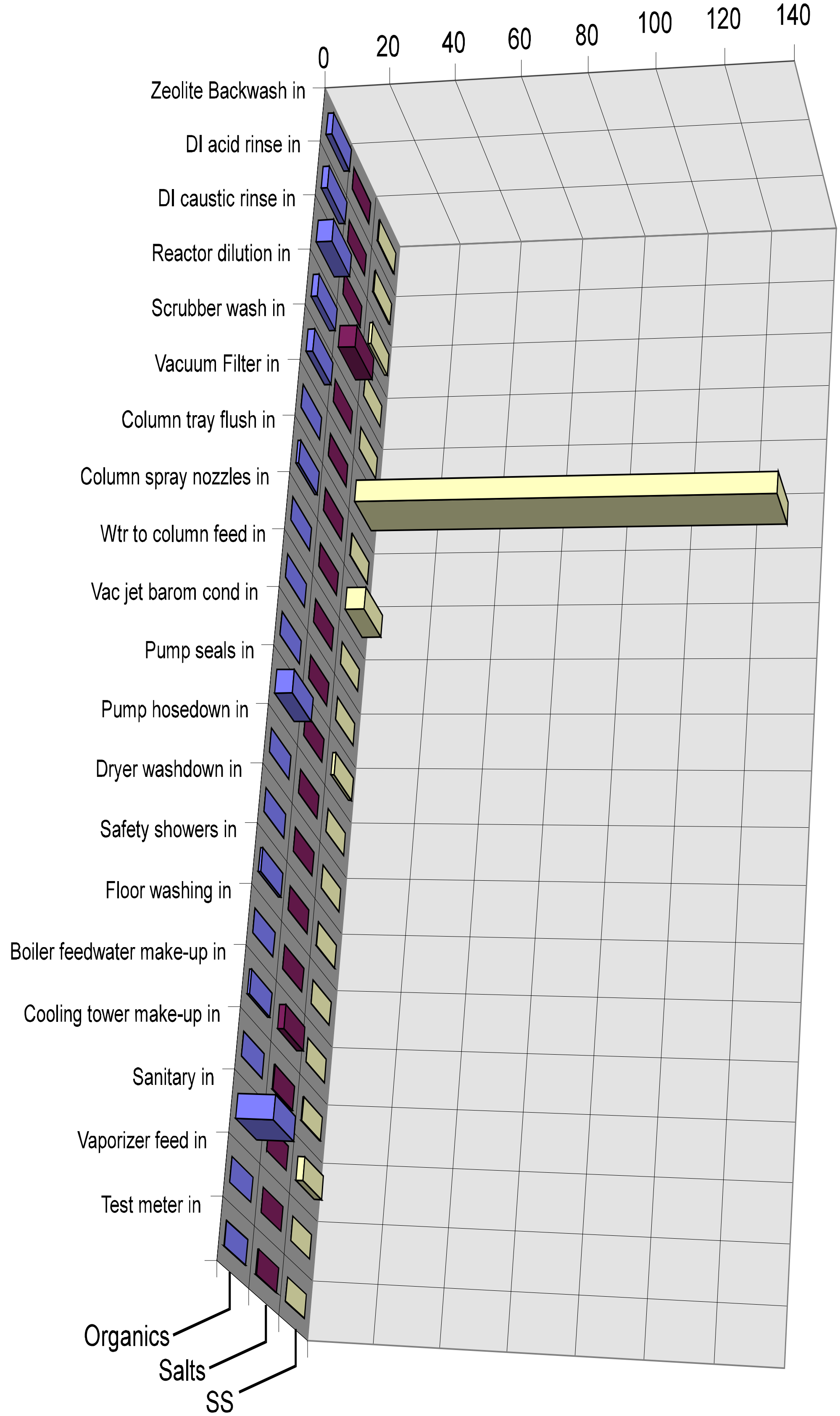
These are developed on the basis of questioning the purpose of every piece of equipment and process step, and asking if it could be accomplished in a different (not necessarily better) way. For example,

- Should scrubber bottoms be refluxed to top tray of column? No
- Column Vaporizer Yes
  Reduce vacuum filter operating temperature? (pro-need less wash water for cake)
  (con-need more steam for drying)
- Could we place a thermocompressor on the dryer exhaust to recover heat (and water)?
- Could some of the streams that end up in the area sump be collected separately?

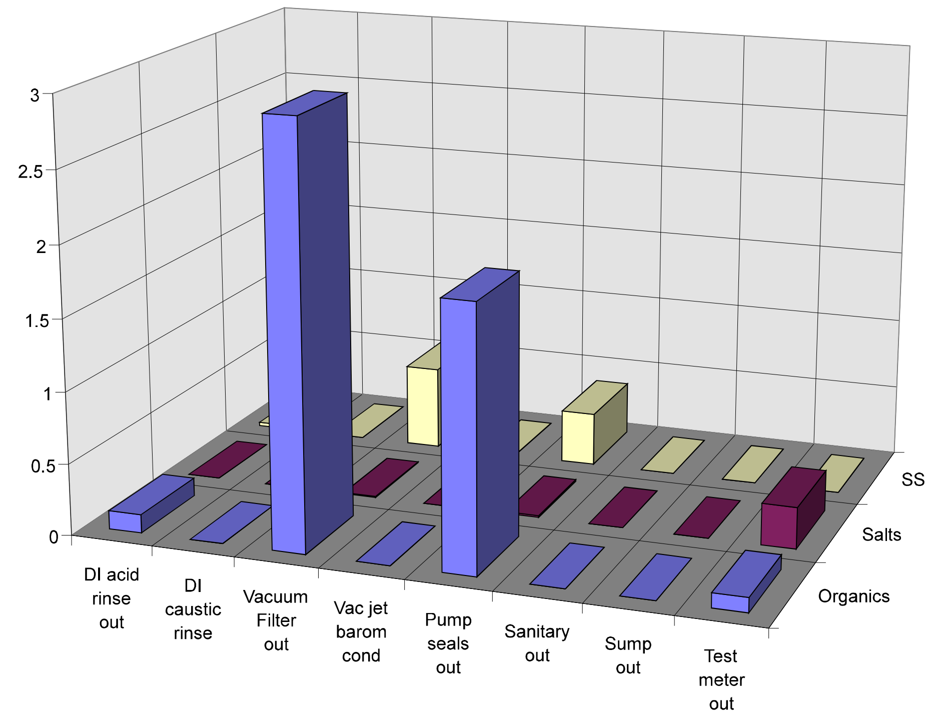
### *Step 7-Establish Design Basis*

Once the preliminary ideas have been developed, the final design basis can be established. This is done by the study team consisting of the pinch analyst(s) and process experts.

- Agree on permissible process modifications.
- Agree on final design values for pinch concentrations.
- Discuss and agree on regeneration options.




**<u>Figure 10</u>: Sensitivity Chart for Inlet Concentrations**




**<u>Figure 11</u>: Sensitivity Chart for Outlet Concentrations**

### *Step 8-Revised Pinch Analysis*

Run the WaterPinch software again, to obtain the revised water reuse strategy. Modify the suggested project list based upon experience and judgment to evolve the final design. In the example case, the final project list was:

| # | Source ID | Sink ID | Savings, gpm | | | | |
|---|---|---|---|---|---|---|---|
| | | | DI | ZW | CW | RW | WW |
| 1 | Scrubber bottoms | Column tray nozzles | - | 6 | - | - | 6 |
| 2 | Vacuum filtrate | Column feed | - | 25 | - | - | 25 |
| 3 | Vacuum filtrate | Column tray flush | - | 7 | - | - | 7 |
| 4 | Vacuum filtrate | Vaporizer feed | 50 | - | - | - | 50 |
| 5 | Pump seals | Dryer washdown | - | - | 42 | - | 42 |
| 6 | DI spent wash | Vac jet barom cond | - | - | - | 54 | 54 |
| 7 | Area Sump | Vac jet barom cond | - | - | - | 21 | 21 |
| 8 | Test meter | BFW makeup | 10 | - | - | - | 10 |
| | | Totals | 60 | 38 | 42 | 75 | 215 |

To summarize, the overall procedure is as follows:

1. Flowsheet
2. Water balance
3. Select key contaminants
4. WaterPinch (Initial)
   - stream selection
   - design concentrations
5. Identify Pinches
6. Process Modifications
7. Revise Design Basis
8. WaterPinch (Revised)
9. Evolve practical design

The final results of our study were:

- Operating Cost Savings = $100K/yr
- Capital Cost of Retrofit = $300K, including Engineering
- Fresh Water Intake Reduced 16%
- Flow to WWT Reduced 21%

The reduction in wastewater flow of 21% did not quite meet the target of 25% needed to avoid investment in new wastewater treatment capacity. We needed an additional 35 gpm of savings. Several options were considered.

a) Two-stage filtration/washing. This could potentially save 100 gpm, but the capital and operating costs were considered too high.

b) Reduce filtration/wash temperature. The polymer particles filter out more easily at lower temperature, which means that less wash water can be used. Potential savings were estimated by the R&D staff at 40 gpm. However, cooler filtration/washing means higher steam consumption in the dryer, which is already operating at its maximum condensing capacity.

c) Divert sanitary sewer to municipal waste treatment. Currently the sanitary sewer flow of 90 gpm is mixed in with process wastewater. It could potentially be collected separately and sent to the municipal sewer, thus offloading 90 gpm from onsite wastewater treatment flow. Sewer segregation and repiping was estimated to cost $150K. Sewer charges would be $50K/year.

It was decided that option (c) was the best one. Total savings in wastewater treatment flow now increased to 215 + 90 = 305 gpm, or 30% of the current load. This more than met the study objectives.

Total capital cost for the proposed solution is

| | |
|---|---|
| Reuse projects | 300 |
| Sewer segregation | 150 |
| | $450K |

Net operating cost savings are

| | |
|---|---|
| Reuse projects | 100 |
| Sewer charges | -50 |
| | $50K/year |

Overall, the study benefits were:

- Avoided $2.5MM in capital cost of expanding the wastewater treatment plant.
- Net operating cost savings of $50K/yr
- Phased capital investment strategy for site infrastructure development.

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